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Holocene Paleolimnology of Mary Gregg Lake, Foothills of the Alberta Rocky Mountains, Canada

by

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A THESIS

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IN

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Michael Hillman

Supervisor

Lorene L. Kennedy

Charles Schweger

Date October 13, 1981

ABSTRACT

Two cores from Mary Gregg Lake (0.08km², 53°7'N, 117°28'W, and 1540m a.s.l.) were submitted to a multi-variable analysis (stratigraphy, sedimentology, geochemistry, and micropaleontology), aiming the reconstruction of its Holocene paleoecological evolution within the context of the surrounding area.

Radiocarbon dates corrected for contamination suggest that the available record spans approximately the last 6000 years. During this period the watershed has been dominantly covered by boreal forest, although more open forest and mesic conditions are indicated before ca. 3500 BP.

Many of the analyzed variables show a similar stratigraphic pattern, the sample data being structured in three basic clusters (zones). They suggest that: between ca. 6000±200 and 3500±200 BP the lake was relatively more eutrophic and supported higher productivity; between 3500±200 and 1000±200 BP, the conditions were more oligotrophic, and the productivity was at its minimum; and after 1000±200 BP, the aquatic system returned to its predominantly mesotrophic state of today.

It is suggested that the cause of these changes is a combination of environmental oscillations and geomorphic conditioning (the lake is located at the water divide of the valley, which limits its volume to a certain maximum). It is hypothesized that the predominance of a longer ice-free season could produce the effects observed before ca. 3500

BP; while a shorter ice-free season (colder?) and possibly wetter conditions could be related to the lake status between 3500±200 and 1000±200 BP. An intermediate situation seems to be dominant in the last 1000±200 years. Human impact has not been a major cause of change in this wilderness area, so far; however, future coal mining operations are scheduled for the vicinity of the lake.

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1. INTRODUCTION

1.1 Objective

Mary Gregg Lake is located in the Foothills of the Canadian Rocky Mountains, adjacent to Jasper National Park, the Mountain Park "refugium" (Packer & Vitt, 1974), the "ice-free corridor" (Rutter & Schweger (eds.), 1980), and within the lease area of an expanding coal mining operation.

The objective of this research was to reconstruct the post-glacial paleoecological history of that lake, using a multidisciplinary analysis of sediment indicators. This can provide not only data for paleolimnological and limnological generalizations, but act as the basis for projections of the future trends in the ecology of the lake, necessary for the proper management of its environs and water resources.

This research was also expected to yield insights into post-glacial chronology, paleoclimatology, and ecological successions of an area, where this information - basic for such disciplines as geology, pedology, archaeology, botany, zoology, climatology, forestry, and wildlife management is lacking.

1.2 Lake systems

The components and processes operating within a lake are very numerous and complex, and constitute an open system, simultaneously linked to the adjacent terrestrial environments, as already clearly pointed out by Rawson (1939).

The abiotic components of a continental water body are linked in a very direct way to the lithologies, soils, climate, and vegetation of the sourrounding area. Groundwater and runoff continuously transport chemical substances and sediments into the basin from rocks and soils. Climatic factors act via precipitation, temperature, and wind, affecting the dilution and distribution of gases and ions, the mobilization of particles, the turbidity, and the water temperature (including thermal stratification). Seasonality and lake morphology are responsible for the structure and dynamic properties (e.g. mixing) of physical and chemical parameters at different times. The vegetation of the watershed regulates important steps of the hydrology of the basin, contributing with dead organic materials being transported into the lake, as well as indirectly affecting soils and microclimate. Natural and anthropogenic fires, and soil disturbances in general, have a capital influence in the terrestrial vegetation communities and, therefore, in the watershed stability and the lake system.

The aquatic biotic components are also directly linked to external influence, particularly climate.

Precipitation-evaporation, light, temperature, and wind are the most prominent physical factors exerting influence upon the organisms on a seasonal basis. In turn, sheltering and shading effects, related to vegetation and topography, also control those parameters.

The abiotic and biotic processes are ultimately linked to the geographical position of the water body, and the local geomorphological controls.

Within the water system, biogeochemical processes are also continuously in effect, determining important characteristics of the sedimentary record (e.g. concentration of silica and trace elements, precipitation of carbonates, redox and mobilization of elements).

Human factors such as pollution, hydrologic alterations, introduction or extinction of species, and resource exploitation, are certainly among the most powerful causes of change on water bodies in modern times.

Indirect effects are always acting, for one factor relates in some way to the others. Thus, a complex web of relationships and feedback actions is the best description of lake systems. Figure 1 depicts schematically such model. Details and examples of watershed-lake systems are given in limnological works such as Cole (1979), Golterman (1975), Hasler (1975), Hutchinson (1957,1967,1975), Likens & Borman (1974), Likens et al. (1977), and Wetzel (1975).

Additionally, these intricate systems change through time from the origin of the lake to the present. The

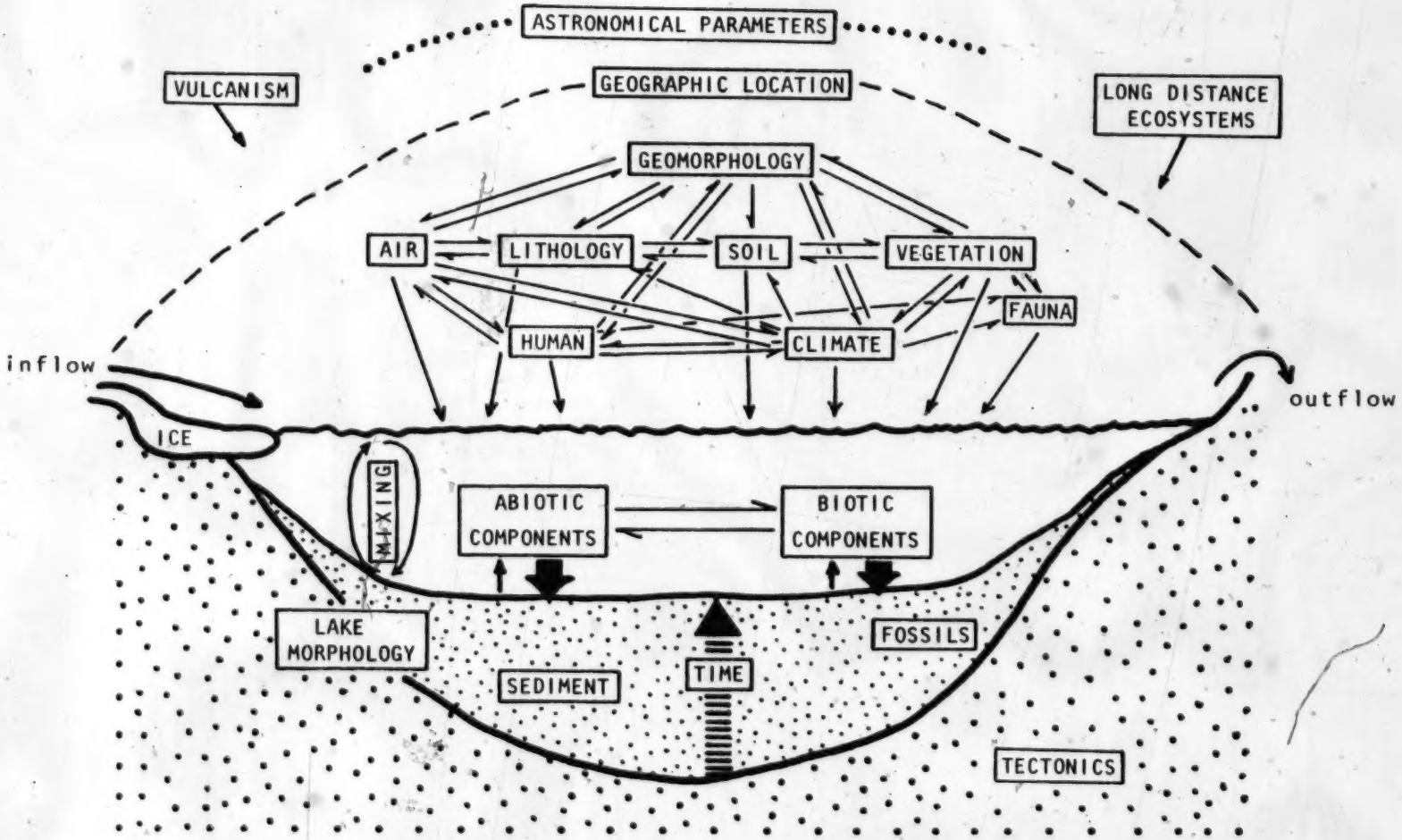

FIGURE 1 - A LAKE SYSTEM.

reconstruction of such ontogenic states is possible to a certain extent (depending upon the conditions of preservation), using the clues provided by the fossils and abiotic components recovered from the sedimentary record, and establishing their relationships. This is the aim of Paleolimnology (Birks & Birks, 1980; Frey, 1969, 1974; Moss, 1980; and Wetzel, 1975).

1.3 Paleolimnology

In addition to providing basic paleoecological information, the ontogeny of lakes is essential for the understanding of present status and, therefore, for the rational management of such resources. Thus, it is the responsibility of the paleolimnologist to offer a reliable reconstruction of the lake evolution. At the present time the number of tools for paleolimnology is diverse, but their use in isolation, although simpler, is not recommended. The larger the number of indicators used in combination, the more accurate will be the conclusions.

The principal indicators used to reconstruct lake histories, are: geological and geomorphological features; bottom sediment characteristics such as structures, granulometry, physical and chemical parameters, and mineralogy; geochemical and biogeochemical data (elemental concentration, plant pigments, and other organic substances); diatoms, pollen/spores, arthropods, porifer

spiculae, and other microfossils; plant remains, molluscs, and other macrofossils; and geophysical properties (stable and radioactive isotopes, and magnetism). Summaries and examples of paleolimnological work can be found in Berglund (1979), Birks & Birks (1980), Bradbury & Hanley (1979), Frey (1969, 1974), Moss (1980), Winter & Wright (1977), and Wetzel (1975). Collections of pertinent papers were published in volume 17 (1969) of the Communications of the International Association of Theoretical and Applied Limnology (Mitt. Internat. Verein. Theor. Angew. Limnol.), and volume 25 (1978) of the Polish Archives of Hydrobiology.

Geological and geomorphological features are generally used to interpret the origin of the water body (Cole, 1979; Reeves, 1968) or previous lake-level fluctuations (e.g. Langford, 1977; Reeves, 1968; Richardson, 1969). Lake morphometry determines important characteristics of the paleolimnological record, particularly focusing of sediments (Kamp-Nielsen & Hargrave, 1978; Wetzel & Manny, 1978).

Bottom sediment characteristics are generally used to indicate changes in the environment of deposition and the watershed (Berglund, 1979; Birks & Birks, 1980; Lerman, 1978; West, 1977), sediment perturbation (Smith, 1959), water-level changes (Digerfeldt, 1975), redox conditions (Lerman, 1978; Wetzel, 1975), and chronology (laminations (Saarnisto in Berglund, 1979), and volcanic ash (many papers cited in Westgate & Gold, 1974)).

Geochemical and biogeochemical data from lake sediments are important in reconstructing the erosional and depositional histories, redox conditions, changes in the environment of deposition, diagenetic changes, paleoproductivity, and human influence.

The most commonly used elements for paleolimnological interpretations are sodium, potassium, calcium, magnesium, aluminum, zinc, copper, iron, manganese, carbon, nitrogen, phosphorus, and sulfur (Bengtsson in Berglund, 1979; Mackereth, 1966; Wetzel, 1975). Trace elements have also been used (Cowgill & Hutchinson, 1966; Hutchinson & Cowgill, 1973; Hutchinson et al., 1970).

Sodium and potassium are related to terrigenous sedimentation, and/or to periods of positive evaporation and saline waters. Calcium and magnesium, when they covary in the same direction, can indicate dolomitic precipitation, terrigenous sedimentation, and/or leaching in the watershed; however, when calcium is high and the Mg:Ca ratio is low, the indication is for preferential precipitation of $CaCO_3$ (induced biologically or not). Aluminum, zinc, and copper, are generally associated with particulate matter, and are usually good indicators of erosion, although Zn and Cu are also related to redox processes (Hallberg, 1972). Iron and manganese can be transported into the lakes either in suspension or in solution. The latter is possible under reducing conditions, Mn being more soluble than Fe (therefore, the Fe:Mn ratio is used as indicator of soil and

hypolimnion redox conditions). Under reducing conditions and the presence of sulfide, Fe also easily precipitates as pyrite, whereas in the presence of phosphate, $Fe_3(PO_4)_2 \cdot 8H_2O$ (vivianite) can be formed diagenetically. Carbon and nitrogen are used to estimate organic matter content. The C:N ratio is an indicator of allochthonous/autochthonous organic matter contribution (high ratios generally suggests preferential allochthonous organic matter). Phosphorus is related either to paleoproductivity and to mobilization processes (erosion and redox). Sulfur in the form of sulfate is generally associated with gypsum evaporites or diagenesis, and in the form of sulfide to reducing conditions and paleoproductivity. Zinc, cadmium, chromium, mercury, and lead are in natural conditions related to terrigenous sedimentation, but can also be used to trace pollution when human input exceeds the amounts usually found in rocks and soils.

Biogeochemical studies have shown that a variety of fossil organic compounds are preserved in lake sediments, such as fatty acids, amino-acids, isoprenoids, alcohols, ketones, sterols, hydrocarbons, carbohydrates, and pigments (Cranwell, 1976; Barnes & Barnes in Lerman, 1978). Photosynthetic pigment derivatives have been the most used in paleolimnological reconstructions to date (Bengtsson in Berglund, 1979; Brown, 1969; Sanger & Gorham, 1970; Swain, 1970; Vallentyne, 1969; Wetzel, 1975). Nondegraded chlorophylls are rare, but pheophytins, chlorophyllides,

pheophorbides, and other degradation products are commonly found in lake sediments (included under the general name of a-pigments). Carotenoids are also common, and some of them are specific to groups of organisms such as the blue-green algae. In summary, fossil pigments serve to indicate the ocurrence of changes in floristic attributes of lakes and their drainage basin, record different algal populations based upon pigment specificity, measure relative abundance of former populations (including productivity), and even indicate changes in the nature of the physical and/or chemical environment.

Compared to the analysis of morphological remains, the limitations of biogeochemical paleolimnology may seem too many, but given the fact that fossils of soft-bodied species are relatively rare, the clues provided by pigment derivatives and other organic substances assume considerable importance. On the other hand, these studies are still in their beginning, and are certainly one of the most fertile fields for research in paleolimnology.

Theoretically, it should be possible to trace the history of diatom populations and communities in a lake, by studying their fossils in bottom sediments, relating the floral and proportional changes to variations of ecological conditions. However, several problems have to be taken into account when using diatoms, many of which have been pointed out by Battarbee in Berglund (1979), Round (1964), and Yuse (1966). Frequent problems, common to other paleoecological

indicators, include differential preservation and representation; erosion, disturbance and contamination of sediments; sampling, processing, counting, statistical and interpretation errors; and exclusive use of percentage data. There are many instances of diatom studies in lake sediments; Bradbury (1971, 1975), Brugam (1980), Duthie & Sreenivasa (1971), Haworth (1969, 1972, 1976, 1977), Hickman et al.(1978), Hickman & Klarer (1981), and Round (1957b, 1961), are but some examples of the use of these important paleolimnological indicators.

Other algal remains have also been recovered and studied in lake sediments, as illustrated by Birks (1976), Hutchinson (1970), Korde (1966), Van Geel (1978), and Whiteside (1965).

Pollen and spore analysis of lake cores is used to provide chronological data and reconstruct paleoecological changes in the region, the watershed, or even the aquatic system, is almost always performed as part of paleolimnological research. Consequently, the literature on the subject is very extensive. Berglund (1979) and Birks & Birks (1980) have reviewed significant contributions. Holland (1980), Heusser (1956), Lichti-Federovich (1970), Ritchie (1976), and Schweger et al. (in press) are pertinent examples for Alberta.

Plant macrofossils, particularly leaves and seeds, are frequently preserved in lake sediments, and have proved very useful in combination with palynology. Wasylikowa in

Berglund (1979) and Birks & Birks (1980) provide recent reviews, and Delcourt et al. (1979) a bibliography. Charcoal fragments have also been used to reconstruct fire history (Swain, 1973, 1978).

Animal remains, principally of arthropods and molluscs, are very important tools in paleolimnology, as reviewed in Berglund (1979), Birks & Birks (1980), Delorme et al. (1977), Frey (1964, 1976), Goulden (1969), Miller (1978), Murray (1979) and Stahl (1969).

Stable isotopes can be used to indicate past hydrological conditions, paleotemperature, and source of carbon and oxygen (Siegenthaler & Eicher in Berglund, 1979). However, geophysical methods are generally employed to establish relative and absolute chronologies. In this respect, paleomagnetism (Mackereth, 1971; Thompson in Berglund, 1979), and especially radiometric dating, are the methods of choice (^{14}C, ^{210}Pb, ^{137}Cs, ^{228}Th:^{232}Th have been used in paleolimnology (Birks & Birks, 1980; Moss,1980)).

There are innumerable examples of multidisciplinary studies in paleolimnology, many of them summarized by Birks & Birks (1980), Cole (1979), Moss (1980), and Wetzel (1975). Additional examples are Battarbee (1978), Bradbury (1978), Elner & Happey-Wood (1980), Forbes (1980), Forbes & Hickman (1978, 1981), Frey (1955), Hickman & Klarer (1981), Hickman et al. (1978), Karrow et al. (1975), Marciniak & Kowalski (1978), and Pennington (1977).

1.4 Mary Gregg Lake environment

Mary Gregg Lake, was named after the half-Indian daughter of the Stoney Chief Cardinal. She married the turn-of-the-century pioneer coal prospector of the region, trapper, and merchant John James Gregg (Ross, 1976).

The lake is located in the Province of Alberta, Canada, Sec. 4, Twp. 48, Rge. 24, west of the Fifth Meridian (NTS 83F/3W), aproximately 53°7'N, and 117°28'W, at an altitude of 1540m a.s.l. (Rocky Mountains Foothills, just east of the Nikanassin Range), within the boundary of Cardinal River Coals Limited lease area. Access to the lake is restricted to a trail of about 1km from Highway 40 (35km south of Hinton and Highway 16).

Its origin is related to glacier activity during the Late Wisconsin Cordilleran Glaciation, with local bedrock structural controls. The result is an elongated water body, plugged by morainic materials. The main axis is oriented in the E-W direction, because corrasion occurred preferentially along the contact (fault) between the dipping Luscar and Blackstone Formations, which form steep slopes of more than 30%, rising about 150m above the level of the lake.

The surficial lithologies of the watershed are mainly Lower Cretaceous continental sandstones, of the Luscar and Mountain Park Formations, in the south slope; and Upper Cretaceous dark marine shales, of the Blackstone, Bighorn, and Wapiabi Formations, as well as colluvium and till (Marlboro Till?), in the north slope (M. Bombin, personal

communication; MacKay, 1929, 1943; Roed, 1975). Some Blackstone Shale and till are also present at the south slope of the east end. Carbonized plant fossils and coal particles occur throughout the Luscar Sandstone outcropping in the south slope. A coal seam is apparently located within 350m from the SW corner of the lake (Hawryluk, 1977).

The soils of the north slope of the valley were mapped as predominantly Distric Brunisols of the Maskuta Association; and those of the south slope as Distric Brunisols and Gray Luvisols of the Robb Association (Dumanski et al., 1972). However, the predominant soils of the lake watershed itself are better classified as Regosols in the Canadian System of Soil Classification, or Entisols in the U.S. System (M. Bombin, personal communication).

The precipitation of the region is about 700-800mm/year. The summers are cool (11°C average), and the winters are cold(-11°C average). Averages of temperature and precipitation data for the last four years, at the Cardinal River Coals' Luscar Mine site (6km from Mary Gregg Lake), is presented in Table 1 . Microclimatically, the radiation and its effects are definitely higher in the south-facing slope. Predominant winds during the summer blow along the valley in the E-W direction, but the strongest winds occur during winter blizzards.

The vegetation of the area is dominantly boreal forest, but the floristic composition varies , depending principally upon the slope and drainage. The north-facing slope supports

Table 1 - Climatic data at Luscar (1977-80)

Mean daily temperature	2.1 ± 0.2 °C
Mean May-Sept. temperature	9.5 ± 3.0 °C
Mean daily max. temp.	8.0 ± 0.4 °C
Mean May-Sept. max. temp.	15.3 ± 3.5 °C
Mean daily min. temp.	-3.8 ± 0.5 °C
Mean May-Sept. min. temp.	3.5 ± 3.0 °C
Max. temperature	28.3 ± 1.7 °C
Min. temperature	-36.5 ± 1.7 °C
Snowfall	269 ± 132 cm
Snow water equivalent	273 ± 40 mm
Rainfall	582 ± 284 mm
Total precipitation	855 ± 255 mm

a white spruce-balsam fir-green alder forest, with abundant mosses (*Pleurozium, Ptilium, Hylocomium*), club-mosses (*Lycopodium*), and horsetail (*Equisetum*), at the ground level. The south-facing slope is covered by a lodgepole pine-green alder forest, with an understory of sparse herbs, and shrubs (including *Juniperus*). Both west and east ends of the lake are poorly drained, and forests of spruce-balsam fir (many young firs can be observed) with an understory of mosses, labrador tea (*Ledum*), lichens and herbs, alternate with thickets of dwarf birch and willow, on organic soils (histosols). Adjacent to the west and east shores, mires occur, with peat accumulation by sedges (*Carex*) and mosses (a collection identified by J. Janssens comprised *Aulacomnium palustre, Bryum sp., Calliergon giganteum, Drepanocladus aduncus, Hylocomium splendens, Pleurozium schreberi*, and *Sphagnum nemoreum*). Slightly higher wet areas of the west side have mats and monticules of *Sphagnum rubrum*. The majority of the trees range in height from 15 to 20m, 10 to 25cm in diameter, and 50 to 80 years in age (Mentz et al., 1973). No major forest fires have been recorded in the watershed for at least the last 20 years.

A sonar bathymetric study done in 1979 by M. Bombin and the author, permitted the elaboration of the map presented in Figure 2 . From this, and aerophotography, the morphometric parameters presented in Table 2 were calculated. The maximum depth was measured after a beaver dam at the east outlet was destroyed in 1978, with a

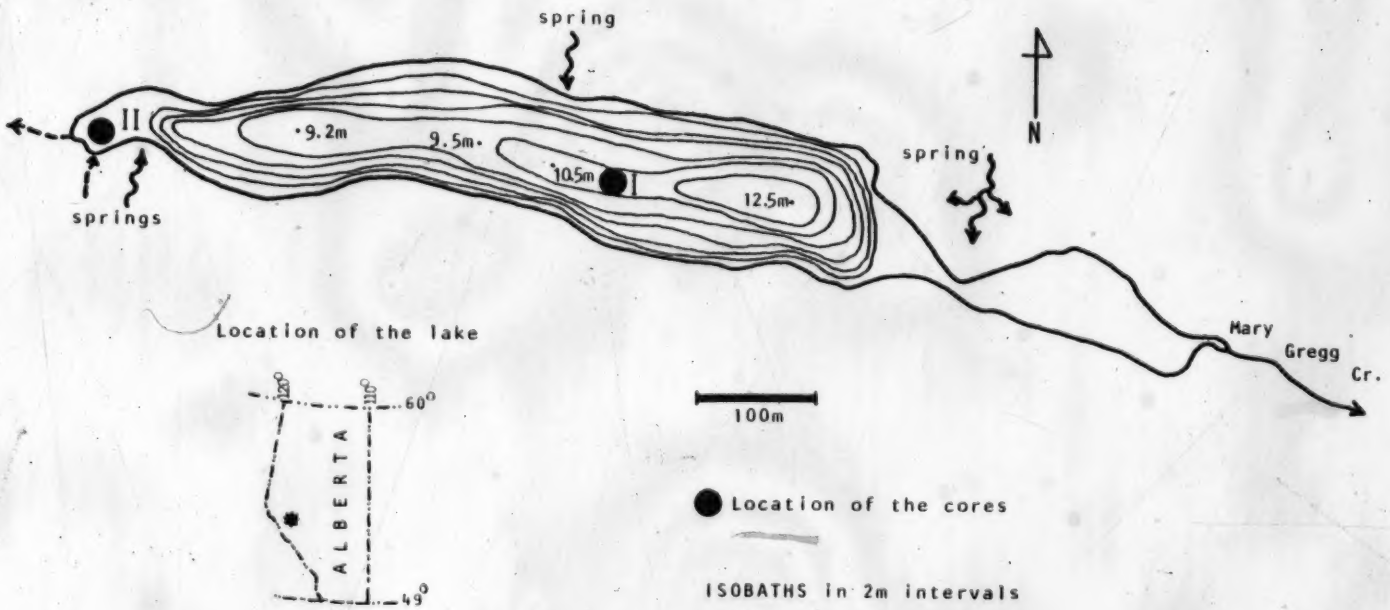

FIGURE 2 - MARY GREGG LAKE BATHIMETRY AND CORING SITES.

Table 2 - Mary Gregg Lake morphometric data

Maximum length	1000 m
Maximum width	127 m
Surface area	80,670 m^2
Area at 2m depth	54,330 m^2
Area at 4m depth	45,330 m^2
Area at 6m depth	35,330 m^2
Area at 8m depth	25,330 m^2
Area at 10m depth	10,330 m^2
Area at 12m depth	3330 m^2
Area at 12.5m depth	1110 m^2
Volume	426,310 m^3
Maximum depth	12.5-13.0 m
Mean depth	5.3 m
Relative depth	3.9 %
Shore line	2200 m
Shoreline development index	2.2
Volume development	1.27
Ellipticity	0.87
Percent mean slope	7.8 %
Morphoedaphic index	22.5 ± 4
Watershed area	≈1,280,000 m^2

resultant drop in previous lake levels of about 0.5-1.0m. The volume development indicates that the bottom morphology is closer to an elliptic sinusoid, which suggests that sediment focusing should not be a major process in this lake (Lehman, 1975).

The water contribution to the lake comes from snow, rain, slope runoff, small springs and probably some ground-water. The lake is at the water divide of the bottom of the valley, having a running water outflow at the east outlet, which forms Mary Gregg Creek (a tributary of McLeod River), but water also seeps through the west mire, draining to Gregg River. This peculiar geomorphic situation of the lake is of great significance for further paleolimnological interpretations, because a positive water budget will probably cause outflow in both directions (eastward and westward), keeping the water level from raising more than to a certain point, determining the dilution of epilimnion nutrients and loss of heat. Contribution of clastics to the lake is mainly through runoff, but the largest spring (SW corner) also brings plant detritus and particles of the Luscar Fm., including coal. Wind is also responsible for plant detritus transport into the lake.

The lake is ice-free from about May through October. Using original measurements, plus information given by Chymko (1980), Dixon (1979), Hawryluk (1977), and Mentz et al. (1973), the profiles of physical parameters presented in Figure 3 were elaborated, using the averages of available

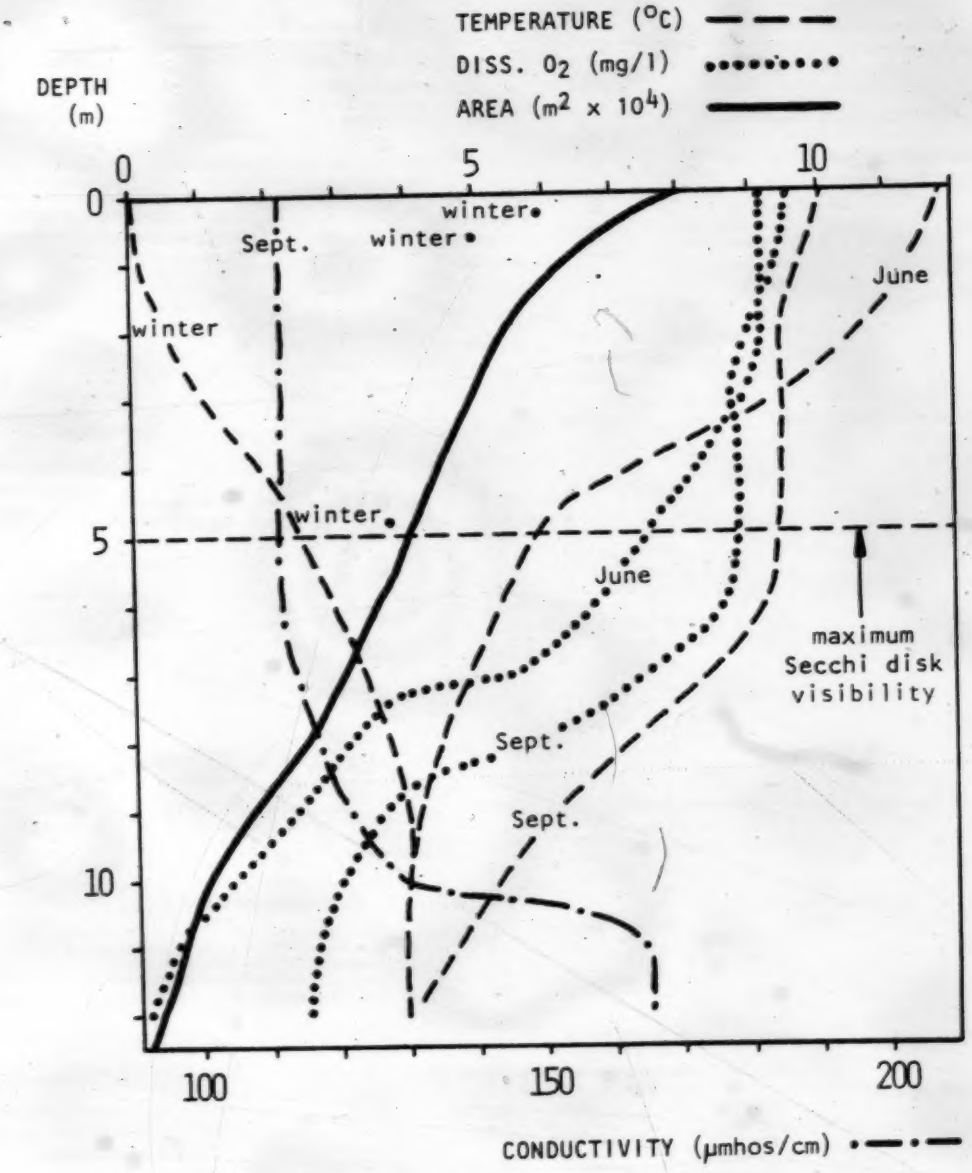

FIGURE 3 - PROFILES OF PHYSICO-CHEMICAL PARAMETERS.

data.

The water pH oscillates within the 7-8 range. Hydrochemical data taken basically from RL & L Environmental Services Ltd. (1981) and M. Hickman (personal communication) is presented in Table 3 .

The bottom type is generally organic mud, but gravel and inorganic mud is found around the shores, and some rocky and sandy bottom occurs in the south littoral zone. Logs are common along the shores, particularly felled by beavers in the south and north shores of the east end.

The benthic communities include: a rich and zonated macrophyte vegetation (optimum growth is found in depths of less than 4.5m) with *Callitriche hermaphroditica*, *Chara sp.*, *Myriophyllum exalbescens*, *Potamogeton pectinatus*, *P. richardsonii*, *Ranunculus spp.*; green and blue-green algae (particularly *Spirogyra* and *Oscillatoria*); diatoms (dominated by several varieties of *Fragilaria*); Sarcodina (*Difflugia*); Bryozoa (*Plumatella*); chironomids and other Insecta; ostracods; amphipods (*Gammarus*); molluscs (*Pisidium* and different species of gastropods); and annelids. A summary of results obtained with an Ekman dredge in the littoral zone (1980), from RL & L Environmental Services Ltd. (1981), is presented in Table 4 . Ekman dredge results in deeper water indicate low total density of organisms (average of 260 organisms/m^2).

The proportional composition of the phytoplankton is subject to wide variability; however, *Ankistrodesmus*,

Table 3 - Hydrochemical data (mg/l)

	Mean*	std. dev.*
Mg	6.30	0.80
Ca	21.30	1.70
Na	10.50	2.00
K	0.90	0.40
Fe	0.11	0.06
Mn	<0.01	-
Cu	≈0.01	-
F	0.16	0.08
Cl	1.30	1.60
Si	1.50	0.70
Sulfate	9.60	4.10
Phosphate	<0.02	-
Nitrite/Nitrate	0.03	0.02
Bicarbonate	104.00	9.00
Alkalinity (as $CaCO_3$)	85.00	7.00
Total hardness	79.50	6.10
Dissolved solids	119.00	23.00
Ignitable diss. sol. (550°C)	60.00	17.00
Total inorganic carbon	25.50	2.10

*Samples taken in June and September, 1978-1980.

Table 4 - Abundance of littoral benthic organisms/m^2 (1980).

	June	September
Oligochaeta	1419-7095	1075-14,104
Hirudinea	0-86	0-43
Acari	0-172	43-688
Amphipoda	0-2064	0-817
Ostracoda	0-43	0-430
Ceratopogonidae	129-2064	0-258
Chironomidae	774-3397	387-5848
Trichoptera	0-387	0-688
Mollusca	0-172	903-8471
Others	0-172	0-86
Total	2322-15,652	2408-31,433

Nemata were very abundant, but not counted

Chlorella, *Gloeocystis*, *Staurastrum*, *Cryptomonas*, *Rhodomonas*, *Dinobryon*, *Asterionella formosa*, *Cyclotella comta*, *Fragilaria crotonensis*, and *Chroococcus*, seem to dominate. A single analysis done on a sample collected in September, 1978, yelded a planktonic concentration of 2.39 micrograms/l of a-chlorophyll, and 0.63 micrograms/l of a-pheophytin.

The zooplankton is dominated by rotifers (*Conochilus*, *Keratella*, *Polyarthra*); water fleas (*Daphnia*, *Bosmina*); and copepods (*Cyclops*). *Cyclops bicuspidatus thomasi* and *Daphnia galeata mendotae* generally account for most of the zooplankton biomass (RL & L Environmental Services Ltd., 1981). A summary of plankton results presented by RL & L Environmental Services Ltd. (1981) is given in Table 5 .

In summary, although the limnological work at Mary Gregg Lake has been only preliminary, the information above indicates that it is meromictic (at least temporarily), mesotrophic, moderately alkaline, and that more than 1% of the incident surface light usually reaches the majority of the bottom of the lake during the ice-free period. The mixing effect of wind agitation is to a large extent counteracted by the lake morphology, abundant macrophytes (which slow down the currents), and maturely treed surrounding area.

Among the necton, insects, fishes, and amphibians have been observed. There is a natural population of brook stickleback (*Culaea inconstans*), while eastern brook

Table 5 - Abundance of plancton (org. or cells/l)

	June*	September*
Cladocera	<1-3	6-16
Copepoda	30-86	20-86
Rotifera	15-274	8-87
Total zooplancton	46-363	34-189
Cyanophyta	tr.-2000	tr.-15,000
Bacillariophyta	12,000-128,000	28,000-88,000
Flagellated algae	24,000-1,288,000	9000-300,000
Chlorophyta	1000-316,000	1000-166,000
Ultraplankton	tr.-2,155,000	tr.-14,000
Total phytoplankton	37,000-3,889,000	38,000-583,000

*Averages of 1978-80

(*Salvelinus fontinalis*), and rainbow trout (*Salmo gairdneri*) have been stocked since 1949 (Dixon, 1979; Hawryluk, 1977). The stickleback and amphipods are the main food items of the two species of trout. Although eastern brook seems to be better adapted for the lake, it has not been stocked since 1953. Natural reproduction of both species is evident, but it is not sufficient to mantain a sport fishery under the present fishing pressure (Hawryluk, 1977).

Human occupation of the area in prehistoric times seems to have been very sparse, and limited to small groups of hunter-gatherers. Only one archaeological site (FgQi-9) was located so far in the Mary Gregg Lake basin (Brink, 1980). It is located in the west shore, and occupies an estimated area of 1500 m^2. Small test holes and surficial collection yielded a basalt core, a Nordegg Formation chert core, a quartzite biface, a basalt biface preform (projectile point?), waste flakes and shatter (predominant lithic material of the site), a few bone fragments from large mammals, and charcoal, which produced a radiocarbon date of 2545±400 BP (S-61892). This assemblage suggests a campsite of the Middle Prehistoric period of Alberta. There is another small campsite (FgQi-7) of unknown age (probably similar to FgQi-9) situated on a terrace along the Gregg River, 1km west of the lake, which also yielded predominantly flakes, and a core of Nordegg Formation chert (Lifeways of Canada Ltd., 1976). A small rockshelter site, 20km southeast of Mary Gregg Lake, was studied by Hall

(1976), who reported small amounts of lithic debitage, and a few finished stone tools, including a small stemmed projectile point, which was associated to a radiocarbon date of about 3750 BP. Historically, human impact upon the lake has been also relativelly restricted. From the beginning of this century until recently, only coal prospectors, trappers, and a few tourists used sporadically the lake resources. In the last 30 years, geological prospection scars are becoming more and more numerous in the watershed.

At present, the all year round recreational value of this lake, is important for several reasons, particularly because it offers excellent scenery, wildlife watching, fishing, conoeing, hiking, cross-country skiing, and picnicking conditions; specially for the workers of the nearby Luscar mines, Cadomin, and for the Hinton area population in general. The spring water is of excellent quality.

The ecological significance of Mary Gregg Lake is enhanced by the fact that it is a unique body of lentic water with its dimensions and characteristics, in a considerable area of the Foothills of the Rockies, and is potentially under coal mining impact in the near future. Uncontrolled and heavier human use during recent years has also become a problem, with landscape disfiguration, garbage accumulation, and alterations in the watershed, being already noticeable.

2. MATERIALS AND METHODS

2.1 The cores

Two bottom cores were taken with a modified Livingstone piston corer (diameter 5cm, length 1m), operated from the ice platform, at the points indicated in Figure 2. Core 1 was obtained in March 1, 1979, and Core 2 in April 15, 1979, respectively under 11m and 0.4m of water.

Immediately after extrusion, the core segments were measured, summarily described, wrapped in plastic film and brown paper (to avoid evaporation, oxidation, and photoreactions). In the laboratory the cores were stored at 4°C to keep alteration at a minimum until sampled.

Before sampling the core segments were precisely measured and the following macroscopic characteristics described: sediment type, Munsell color, texture, structures, tephras, macrofossils, and any other particulars.

2.2 Core sampling

After inspection for obvious contamination, the surface of the sediment cores were cleaned by scraping, generally at 10cm intervals, and the aliquots referred in Table 6 were sampled.

Sixteen samples of about 100-150cm³ were taken at selected intervals for radiocarbon dating, oven dried at

Table 6 - Core samples

Wet volume (cm^3)	Analyses
1	Density, water content, organic matter, carbonates
1	Diatoms, Chrysophyta cysts
1	Pollen/spores, pyrite spherules
1	a-pigments, carotenoids, other algae, Cladocera
5*	Na, K, Ca, Mg, Al, Zn, Cu, Fe, Mn, P, S, N
5-7*	pH in 0.01M $CaCl_2$, granulometry, macroremains, sand/gravel stereomicroscopy
100-150	Radiocarbon dating

*Freeze dried after sampling

60°C, weighed, and wrapped in aluminum foil, before sending to the Geological Survey of Canada Radiocarbon Dating Laboratory, Ottawa, for analysis.

2.3 Surface samples

In order to provide comparative data, three sets of surface samples were obtained from:

- Rocks and soils for geochemical analyses
- Lake sediment, soils and moss cushions for palynology;
- Lake sediment for diatoms and Chrysophyceae cysts.

2.4 Analytical procedures

Density was calculated by weighing 1cm³ of wet sediment. In the same sample, water content (unbound water) was found by differential weight after oven drying at 105°C overnight; the organic matter was estimated by weight loss at 550°C for 1h; and the carbonate after 3h at 950°C (Wetzel, 1970). Carbon content was approximated by dividing the organic matter results by a factor of 1.8 (McKeague, 1978).

Siliceous microfossils (diatoms, Chrysophycea cysts, etc.) were prepared by the method outlined by Hickman & Klarer (1981), which consists of oxidation of the organic matter with a mixture of hydrogen peroxide, potassium dicromate, and sulfuric acid, followed by repeated washing with distilled water. Known volumes of a homogeneous

suspension are then pipetted and let to dry onto coverglasses, and slides mounted with Hyrax resin (Custom Research & Development Inc., refractive index 1.65). The slides were scanned until about 600 diatom frustules/valves were identified under oil immersion (1000x magnification, binocular microscope), basically in accordance with Cleve-Euler (1951-1955), Hustedt (1930), and Patrick & Reimer (1966, 1975). The concentration of diatoms per cm^3 was estimated using the known area of the microscope field, and the recorded number of fields.

Pollen and spores were prepared for counting by a similar procedure to that outlined by Faegri & Iversen (1975). The standard treatments included HCl, NaOH, HF, and acetolysis mixture (acetic anhydride and sulfuric acid). A contaminant tablet of *Eucalyptus* pollen (batch 903722, mean=16,180±1460 pollen grains/tablet) was added before processing to estimate the fossil pollen concentration (Benninghoff, 1962). Slides were mounted with silicone oil (viscosity 2,000 cs, refractive index 1.4). By plotting the number of grains counted for new taxa to appear in random samples, it was determined that about 400 grains/level was the optimum number for the purposes of this work. Therefore, this size of subsample was counted and identified, under a 400x or 600x binocular microscope, using basically the keys of Habgood (1978), Faegri & Iversen (1975), and McAndrews et al. (1973), and the reference collection of the Laboratory of Paleoenvironmental Studies (Department of Anthropology,

University of Alberta). Aquatic plant pollen was not included in the total sum for calculation of terrestrial pollen percentages. Pyrite spherules were counted in the same slides.

The sedimentary pigment degradation products (SPDP) were analysed according to Moss (1967, 1968) and Vallentyne (1955). After addition of magnesium carbonate to prevent pheophytinization, SPDP were extracted from 1cm³ aliquots of sediment in known volumes of a 90% aqueous acetone solution. Spectrophotometric optical density readings at 665nm were used to estimate the sedimentary chlorophyll degradation products (SCDP); and at 480nm to estimate total carotenoids (TC). Blank and turbidity corrections were made at 750nm. One pigment unit is equal to an optical density of 0.100 through a path length of 1cm, of an extract from 1g of dry sediment in 10ml of 90% acetone.

After fossil pigment extraction, subsamples of sediment were mounted with glycerol between slide and coverglass, and scanned under a binocular microscope (average of 200 fields per slide), for a semi-quantitative estimation of other algae and Cladocera remains.

Sediment elements were solubilized by acid digestion of 100mg freeze dried samples in a sealed teflon bomb at 135°C for 2h, with a mixture of aqua regia and hydrofluoric acid, followed by addition of boric acid to solubilize metal fluorides and stabilize the solution (Loring & Rantala, 1977). Sodium and potassium concentrations were determined

by flame photometry; and those of calcium, magnesium, aluminum, zinc, copper, iron, and manganese by atomic absorption spectrophotometry. Total P (in the form of phosphate) was analyzed spectrophotometrically by the ascorbic acid method (American Public Health Association et al., 1976). Total S (as sulfate) was determined by the turbidometric method (slightly modified from McKeague (1978) by skipping the extraction steps).

Total N was extracted by micro-Kjeldahl digestion of 100mg of freeze dried sediment, and determined by a Technicon autoanalyzer (American Public Health Association et al., 1976).

The pH of freeze dried sediment samples of known weight was measured in a 0.01 M $CaCl_2$ solution (McKeague, 1978). After the pH determination, the sample was screened through sieves of 2mm and 0.062mm to obtain a simple granulometric distribution of gravel, sand, and fines (silt + clay) by weight. The sand/gravel fractions, collected on the sieves, were summarily studied under a stereomicroscope (maximum magnification 30X).

The radiocarbon dates were obtained by carbon dioxide proportional counting at the Geological Survey of Canada Radiocarbon Dating Laboratory, Ottawa, according to the methods described by Dyck (1967) and Lowdon et al. (1977).

3. RESULTS

3.1 Core 1

3.1.1 Core segments

Eight drives were accomplished with the piston corer, for a total of 7.6m of sediment. The length of the respective core segments is given in Figure 4 . The basal 4cm of the first drive were lost, and the top 3cm were considered unsuited for analysis (too fluid and disturbed).

3.1.2 Stratigraphy

3.1.2.1 Sediment type

A schematic column of sediment types, including structures, is presented in Figure 4. As a whole, the 700cm of Holocene sediments recovered in Core 1 are predominantly fine-grained organic mud (ooze). Clear laminations start just above the contact with the bedrock shale, and fade around 290cm. Some of the light laminations are marly, specially the ones of the bottom 100cm. Coarse materials are easily visualized from 550cm down, particularly between 590cm and 550cm, where vivianite is also visible. Three tephra layers are present, but only the thickest and purest one, between 455-457cm, is certainly a primary lacustrine deposit. The sediment has a strong sulfurous putrid odor throughout.

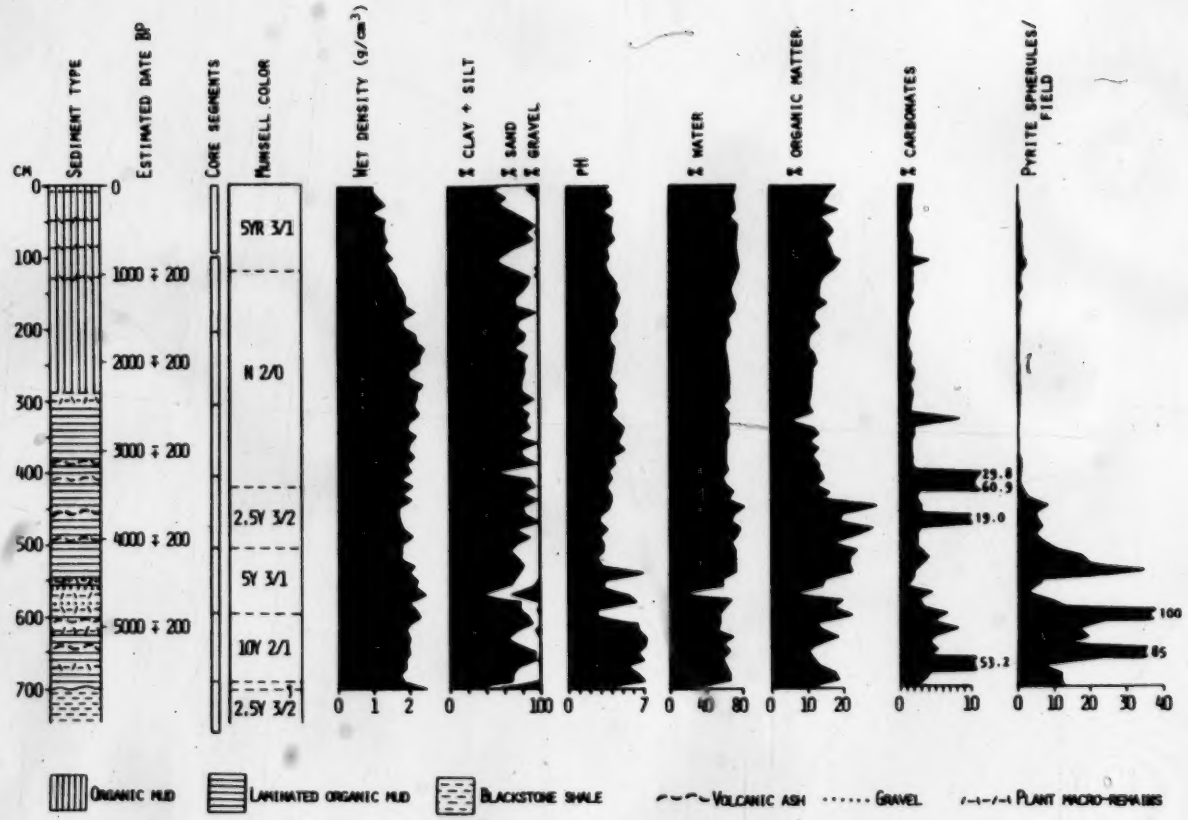

FIGURE 4 - CORE 1 STRATIGRAPHY.

3.1.2.2 Sand/gravel stereomicroscopy

From 700 to 550cm the mineral gravel fraction is much coarser (some pieces >2cm), and composed of relatively unweathered Blackstone Shale chips; while above 550cm this is not found, and some granules seem to be diagenetically and/or coprogenetically cemented. Cleaner sand occurs at the contact between these two units (550cm), and iron-rich concretions appear at the basal contact with the Blackstone Shale (700cm).

Volcanic ash shards are present below the 250cm level, being particularly abundant at the 610-600, 490, 460-450, 410, and 390-380cm levels.

Coal particles are not clearly observed in this core, with the exception of a possible occurrence at 370cm.

Charcoal fragments are more abundant below 220cm.

Mollusc fragments occur at 90-80cm.

Remains of beetles are apparently more abundant in the upper 400cm.

Chitin cuticules occur throughout, more prominently at 190-180cm.

Plumatella statoblasts apparently occur throughout the core but are definitely more abundant below 420cm and above 120cm.

Daphnia hiphippia have the same stratigraphic distribution as the bryozoan statoblasts.

Plant detritus is more abundant below 550cm (coarser) and between 120 and 40cm, being particularly scarse between

290 and 120cm. Mosses occur at 430, 130, 120, and 70cm.

Few ostracods are present exclusively in the bottom 100cm and upper 50cm.

Small fish bones occur commonly below 600cm.

Sand-size diatoms are common between 550 and 460cm, and again between 420 and 170cm. These include species of *Campylodiscus*, *Melosira*, *Stauroneis*, *Gyrosigma*, and *Synedra*. *Campylodiscus hybernicus* and *Melosira teres* are dominant between 420 and 170cm.

3.1.2.3 Wet color

Figure 4 displays the stratigraphic changes in the predominant Munsell color of wet and relatively unoxidized sediment. There are three basic color zones; the first one from the bottom to about 420cm presents variations of the Y hue (very dark brown and olive grays); the next zone from 420-120cm have a N hue (black); and the upper zone from 120cm to the surface is on the YR hue (very dark grey).

3.1.2.4 Density

The stratigraphic plotting of sediment density (Figure 4), agrees with the visual observation that compactation decreases markedly from 170cm upwards. Only when the more compact fine mineral sediment fraction or gravel increase, does the density surpass $2g/cm^3$.

3.1.2.5 Granulometry

The granulometry of the core is dominated by clay and silt (Figure 4). Between 470cm and 130cm the coarse (>0.062mm) fraction rarely surpasses 20%, and there is no gravel between 550-130cm. Noticeable peaks of coarse gravel occur only at 700-690cm, 620cm, and 600-550cm. Finer gravel is also present in small amounts in the top 10cm.

3.1.2.6 pH

Between 530cm and the surface, the sediment pH is acidic, oscillating within the 3-5 range (Figure 4). In the bottom 260cm it varies to greater values, up to pH 7.

3.1.2.7 Water content

Interstitial water generally varies in the sediment between 60-80% (Figure 4). The section dominated by finer mineral sediments (400-170cm) averages about 60%. At the 700cm level (contact with shale) the water content is 20%, and at 570cm (peak of gravel and sand) it is 3.5%.

3.1.2.8 Organic matter

The organic matter percentage spectrum (Figure 4) can be described as delineating three main stratigraphic zones. The oldest one, from 700 to 440cm, exhibits wider oscillations and averages more than 15% of O.M.; the middle zone, from 440 to about 130cm, has O.M. values averaging less than 15%; and the top zone from 130cm up again averages more than 15% O.M., although values never surpass 20% as

some of the levels of the lowermost zone.

3.1.2.9 Carbonate

Carbonate concentrations are generally higher than 2% below 400cm (Figure 4), with marked peaks at 670, 620, 470, 420, and 410cm. Above the 400cm level, carbonate percentages are generally lower than 2% (only the 330 and the 110cm samples are exceptions).

3.1.2.10 Pyrite spherules

The number of pyrite spherules per field is clearly higher in the basal portion below 430cm (Figure 4). In the remainder portion of the core the number of spherules is generally lower than 1 per field. There is a slight increase at the 120cm level to more than 2 spherules/field, trending back to less than 1 spherule/field towards the surface.

3.1.2.11 Radiocarbon dates

Ten ^{14}C dates were obtained on a sequence of core segments, through the Geological Survey of Canada Radiocarbon Laboratory. All samples were pretreated with HCl. The results are given in Table 7

3.1.3 Biogeochemistry

3.1.3.1 Carbon

The carbon concentrations presented in Figure 5, being obtained as a constant function of the organic matter content, have an spectrum identical to the latter.

Table 7 - Core 1 radiocarbon dates

Depth (cm)	Lab. N°	Date BP ± 1σ	$^{o}/_{oo}$ $\delta^{13}C$	Corr. date BP
0-10	GSC-3278	2930 ± 110	-	-
40-50	GSC-3056	2540 ± 150	-29.5	2460 ± 150
150-155	GSC-3091	4640 ± 120	-28.3	4590 ± 120
200-205	GSC-2941	5380 ± 130	-30.3	5300 ± 130
400-405	GSC-2894	6180 ± 120	-28.9	6110 ± 120
552-558	GSC-2901	7280 ± 100	-28.7	7220 ± 100
625-630	GSC-3079	8210 ± 100	-30.3	8120 ± 100
664-669	GSC-2892	7170 ± 70	-29.4	7100 ± 70
677-683	GSC-3061	7540 ± 90	-28.8	7480 ± 90
690-697	GSC-2935	10,400 ± 220	-	-

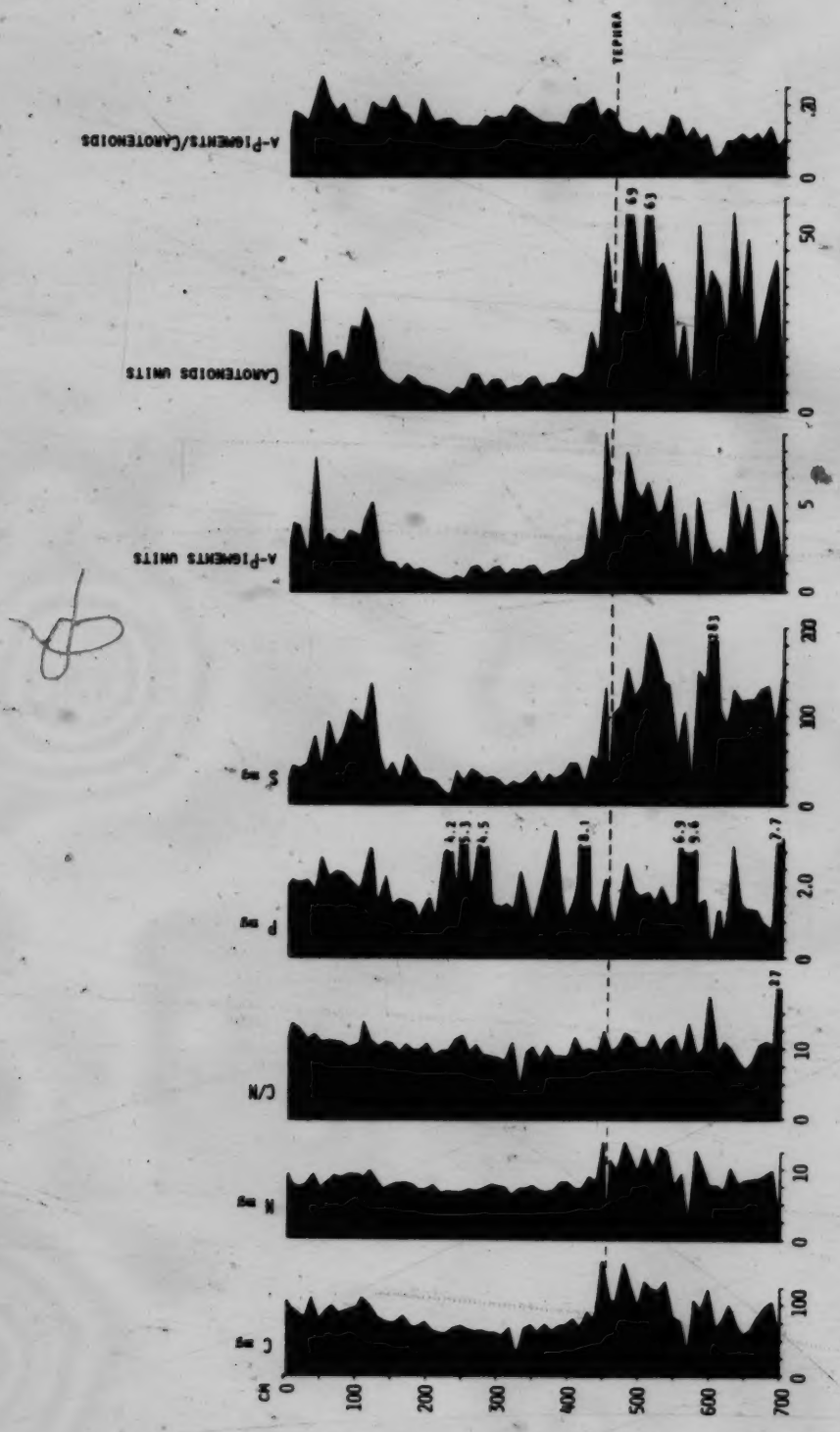

FIGURE 5 - CORE 1 BIOGEOCHEMISTRY (/g dry wt.).

3.1.3.2 Nitrogen

The N results, summarized in Figure 5, are distributed in three zones. The lowest one, from 420cm down, have generally values surpassing 7.5 mg/g dry wt. (many exceed 10 mg/g dry wt.), with the exception of the 455-457cm volcanic ash, and at the gravel peak levels. The next zone, from 420 to 130cm, have N values generally lower than 7.5 mg/g dry wt.; and the top zone, from 130cm up, averaged N values slightly higher than 7.5 mg/g dry wt.

3.1.3.3 C:N ratio

With the exception of a few levels (notably the bottom ones), the distribution of the C:N ratio averaged about 10 (Figure 5). A trend towards a depression in the spectrum to values lower than 10 is noted in the middle section. An exceptionally high value occurs at the interface between the limnic sediment and the basal shale.

3.1.3.4 Total phosphorus

The P stratigraphic profile is quite serrated (Figure 5), although most values fall between 1 and 3 mg P/g dry wt. Two very low indentations occur at 620 and 600cm. Three peaks exceed 6 mg/g dry wt. (700, 570, and 420cm), and three other exceed 4 mg/g dry wt. between 280 and 230cm. In the upper 120cm this element is generally higher than 2 mg/g dry wt.

3.1.3.5 Sulfur

The sulfur stratigraphic spectrum, depicted in Figure 5, shows three different zones. The bottom one, from 440cm down, has high values of sulfur, generally more than 80-100 mg/g dry wt. (exceptions made to the gravel and to the 455-457cm volcanic ash levels). The intermediate zone, from 440 to 130cm, has relatively low values, generally lower than 40-50 mg/g dry wt. The upper zone, from 130cm to the sediment surface, has again higher values of S, generally surpassing the 40-50 mg/g dry wt. concentration.

3.1.3.6 a-Pigments

The three-zone pattern of other indicators is also clear in the a-pigment stratigraphy (Figure 5). With the exception of the lowest level, from the bottom of the core to 420cm, the a-pigments yield more than 2 units/g dry wt. The middle zone, from 420 to 130cm, presents less than 2 units of a-pigments/g dry wt. (some levels even less than 1 unit). The third zone (upper 130cm), yields again more than 2 units/g dry wt.

3.1.3.7 Carotenoids

The carotenoid profile is almost analogous to that of the a-pigments (Figure 5). That is, there are three basic zones. The basal one (420cm down) exhibits generally more than 10 units/g dry wt., although wide fluctuations occur, many peaks having more than 40 units/g dry wt., while the gravel levels have the lowest values of the core. The

intermediate zone (420-130cm) has the lowest values, generally below 10 units/g dry wt. The upper zone (above 130cm) again have values surpassing 10 units/g dry wt., although not as pronounced as in the basal one (only two peaks surpass 25 units/g dry wt.).

3.1.3.8 a-Pigments:Carotenoids ratio

The stratigraphic spectrum of the a-Pigments:Carotenoids ratio, depicted in Figure 5, indicates two different patterns. A basal zone, from 700 to 470cm, have ratios generally below 0.15. Above 470cm the ratios are generally higher than 0.15.

3.1.4 Metals

3.1.4.1 Sodium

As a rule, Na remains fairly constant throughout the core, with values between 2.5 and 5.0 mg/g dry wt. (Figure 6) . The exception is the 455-457cm volcanic ash level (32.9 mg/g dry wt.) and two peaks after it at 440cm (7.5 mg/g dry wt.) and 410cm (7.9 mg/g dry wt.).

3.1.4.2 Potassium

The stratigraphic profile of K has a twofold pattern (Figure 6), with values generally lower than 20 mg/g dry wt. in the basal portion (below 430cm), and higher than 20 mg/g dry wt. in the upper part (above 430cm).

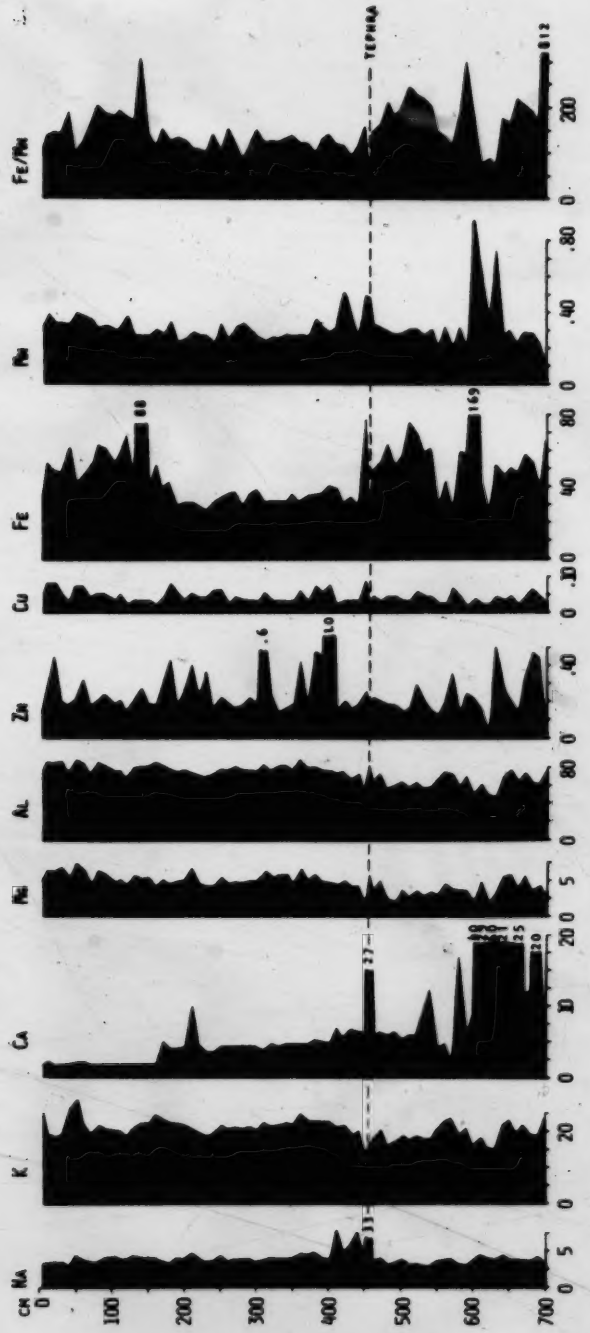

FIGURE 6 - CORE 1 METALS (mg/g dry wt.).

3.1.4.3 Calcium

The general trend of Ca is to decrease from the base of the core up (Figure 6), although the basal gravel peaks also have low values. Notable peaks occur at the 455-457cm volcanic ash horizon, and below the 600cm level. A three fold pattern is also dicernible: below the 410cm level Ca values average more than 5 mg/g dry wt.; between 410 and 170cm the values fall generally between 5 and 2.5 mg/g dry wt.; and in the upper 170cm the values are always below 2.5 mg/g dry wt.

3.1.4.4 Magnesium

The Mg stratigraphic profile is similar to that of K, in having a twofold pattern (Figure 6). Underneath the 430cm level the Mg values generally oscillate below 5 mg/g dry wt. Above the 430cm level they average 5 mg/g dry wt. or more.

3.1.4.5 Aluminum

A trend comparable to those of K and Mg is also visible in the Al stratigraphic spectrum (Figure 6). In the basal section (below 430cm) the Al concentration oscillates around 60 mg/g dry wt.; while in the upper 430cm it tends to average 80 mg/g dry wt.

3.1.4.6 Zinc

The Zn profile does not seem to have any clear trend (Figure 6), remaining erratic throughout, with two main peaks at 400cm (1.02 mg/g dry wt.) and at 310cm (0.61 mg/g

dry wt.). Exceptionally low values coincide with the 455-457cm volcanic ash level, the 620cm level, and the 700cm basal sample.

3.1.4.7 Copper

Copper also does not show any particularly noticeable trend (Figure 6); moreover, it lacks prominent peaks. The Cu:Zn ratio, although calculated, is omitted for it does not provide any clear information.

3.1.4.8 Iron

The stratigraphic profile of Fe shows a threefold pattern (Figure 6). The oldest zone, from 700 to 440cm, has relatively high values of Fe (generally more than 40 mg/g dry wt.). The middle zone, from 440 to 180cm, has relatively low Fe content (less than 40 mg/g dry wt.); while the upper portion has again higher values of Fe (more than 40 mg/g dry wt.). Conspicuous peaks occur at 600cm and 140cm.

3.1.4.9 Manganese

There is no well defined pattern in the Mn spectrum (Figure 6). Between the bottom and 410cm values tend to have wider oscillations, with a low at the very bottom, and four peaks at 630, 600, 450, and 420cm respectively. Between 410cm and 130cm the profile is slightly depressed below the 0.30 mg/g dry wt. line. A discret bulge above the 0.30 mg/g dry wt. line occurs in the last 130 cm.

3.1.4.10 Fe:Mn ratio

The Fe:Mn ratio follows very closely the iron profile (Figure 6) and, therefore, the threefold pattern is also clearly discernible.

3.1.5 Pollen and spores

The following 52 palynomorph taxa were identified in Core 1:

Abies

Alnus

Anemone canadensis

Arceuthobium americanum

Artemisia

Betula

Bothrychium

Bryophyta

Campanulaceae

Caprifoliaceae

Caryophyllaceae

Chenopodiaceae/Amaranthaceae

Compositae (Tubuliflorae)

Cyperaceae

Dicranaceae

Dodecatheon

Ephedraceae

Equisetaceae

Ericaceae

Eriogonum

Fragaria vesca

Gallium

Juniperus

Larix/Pseudotsuga

Ledum

Lycopodiaceae

Monolete spores

Myricaceae/Corylaceae

Myriophyllum

Onagraceae

Picea

Pinus (diploxylon)

Poaceae (=Gramineae)

Polygonaceae

Polypodiaceae

Populus

Potamogeton

Ranunculus

Rosaceae

Rumex

Salix

Sarcobatus

Saxifragaceae

Scrophulariaceae

Sedum

Shepherdia canadensis

Sphagnaceae

Thalictrum

Trilete spores

Tsuga heterophylla

Tsuga mertensiana

Umbelliferae

Only *Pinus*, *Picea*, *Abies*, *Alnus*, *Betula*, and Cyperaceae exceed 2% among the terrestrials; while only *Myriophyllum* is represented with more than 2% among the aquatics. Their stratigraphic profiles are summarized in Figure 7.

The arboreal pollen is generally more than 95% throughout the core, and it is definitely dominated by pine (60-80%), spruce (10-20%), and alder(about 10%). There is little change in the profiles of these pollen types, specially if a 95% confidence interval of 3-4% is considered. The only suggestion of the available data is a slightly higher average proportion of pine and fir, and lower of spruce, above 430cm level; while alder is lower in the upper 260cm. A marked peak of alder occurs at the 490cm level.

Among the pollen types with less than 2%, Myricaceae/Corylaceae do not occur above the 400cm level (Figure 7).

The only prominent aquatic, *Myriophyllum*, has isolated peaks at the 680 and at the 20cm levels, but a significant bulge occurs between 570 and 400cm (with an identation immediately above the 455-457cm volcanic ash fall).

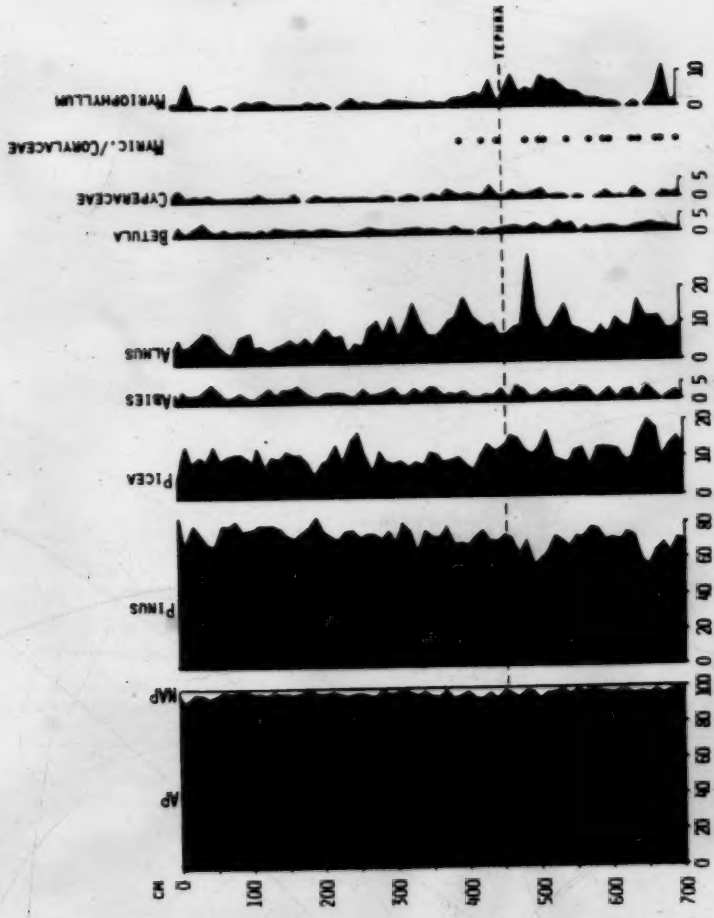

FIGURE 7 - CORE 1 PERCENTAGE POLLEN DIAGRAM.

Cyperaceae are more continuously distributed, and averaging more than 2%, between 510 and 380cm.

Dwarf-birch is the only *Betula* occurring locally today, but it is not possible to decide, on the basis of the available pollen data, if that was also the case in the past.

The concentration pollen diagram (Figure 8) displays very serrated profiles. As a generalization it is possible to say that, from the 390cm level up, there has been a trend towards lower pollen concentrations, with the exception of the uppermost level where they are high again (particularly *Pinus*, *Picea*, *Alnus*, and NAP).

The average of taxa per level is 15, with a range of 11-22; and the percentage of indeterminable palynomorphs averaged 2%. Pre-Quaternary palynomorphs are never present in the samples.

3.1.6 Diatoms

A total of 186 diatom taxa were identified to the level of variety in Core 1, consisting of (varietal names are omitted when identical to the specific names):

Achnanthes clevei Grun.

A. clevei var. *rostrata* Hust.

A. conspicua A. Mayer

A. exigua Grun.

A. hauckiana Grun.

A. lanceolata (Bréb.) Grun.

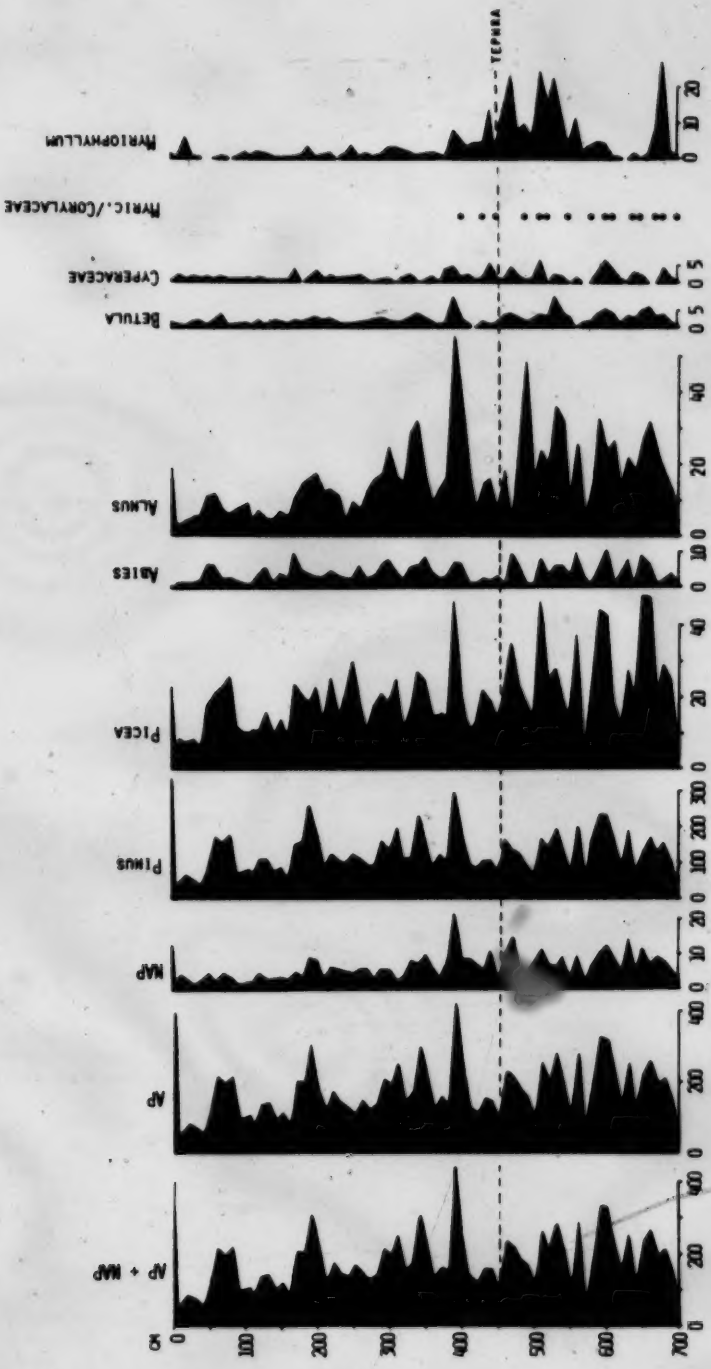

FIGURE 8 - CORE 1 CONCENTRATION POLLEN DIAGRAM (POLLEN/CM^3 x 10^3).

A. lanceolata var. *elliptica* Cl.

A. lanceolata var. *rostrata* Hust.

A. linearis W. Smith

A. marginatula Grun.

A. minutissima Kütz.

A. peragalli var. *fossilis* Temp. & Perag.

A. saxonica Krasske

Amphora coffaeiformis Agardh

A. delicatissima Krasske

A. montana Krasske

A. ovalis Kütz.

A. ovalis var. *lybica* (Ehr.) Cl.

A. ovalis var. *pediculus* Kütz.

A. perpusilla Grun.

Asterionella formosa Hass.

Caloneis bacillum (Grun.) Mereschk.

C. silicula (Ehr.) Cl.

Campylodiscus noricus var. *hibernicus* (Ehr.) Grun.

Ceratoneis arcus Kütz.

Cocconeis diminuta Pant.

C. disculus Schum.

C. hustedtii Krasske

C. placentula Ehr.

C. placentula var. *euglypta* (Ehr.) Cl.

C. placentula var. *lineata* (Ehr.) Cl.

Cyclotella comta (Ehr.) Kütz.

C. kutzingiana Thwaites

C. meneghiniana Kütz.

C. stelligera Cleve & Grun.

Cymatopleura solea (Bréb.) W. Smith

C. solea var. *regula* (Ehr.) Grun.

Cymbella cistula (Hempr.) Grun.

C. cymbiformis (Kütz.) V.H.

C. cuspidata Kütz.

C. ehrenbergii Kütz.

C. heteropleura (Ehr.) Kütz.

C. microcephala Grun.

C. minuta var. *selesiaca* (Bleish ex Rabh.) Reim.

C. naviculiformis Auerswald

C. prostrata (Berkeley) Cl.

C. sinuata Greg.

C. thumensis (Mayer) Hust.

C. turgida (Greg.) Cl.

C. ventricosa Kütz.

Diatoma anceps (Ehr.) Grun.

D. elongatum Agardh.

Diploneis elliptica (Kütz.) Cl.

D. oculata (Bréb.) Cl.

D. pseudovalis Hust.

D. puella (Shum.) Cl.

Epithemia argus (Ehr.) Kütz.

E. sorex Kütz.

E. turgida var. *granulata* (Ehr.) Grun.

E. zebra (Ehr.) Kütz.

E. zebra var. *porcellus* (Kütz.) Grun.

E. zebra var. *saxonica* (Kütz.) Grun.

Fragilaria aequalis Mayer

F. brevistriata Grun.

F. brevistriata var. *inflata* (Pantocsek) Hust.

F. capucina Desm.

F. capucina var. *acuta* Grun.

F. capucina var. *mesolepta* (Rabh.) Grun.

F. construens (Ehr.) Grun.

F. construens var. *binodis* (Ehr.) Grun.

F. construens var. *subsalina* Hust.

F. construens var. *venter* (Ehr.) Grun.

F. crotonensis Kitton

F. leptostauron (Ehr.) Hust.

F. leptostauron var. *dubia* (Grun.) Hust.

F. pinnata Ehr.

F. pinnata var. *interscedens* (Grun.) Hust.

F. vaucheriae (Kütz.) Peters.

F. virescens Ralfs

Gomphonema acuminatum Ehr.

G. acuminatum var. *brebissonii* (Kütz.) Cl.

G. acuminatum var. *coronata* (Rhr.) W. Smith

G. acuminatum var. *pusilla* Grun.

G. angustatum (Kütz.) Rabh.

G. clevei Fricke

G. constrictum Ehr.

G. constrictum var. *capitata* (Ehr.) Cl.

G. gracile Ehr.

G. intricatum Kütz.

G. longiceps var. *subclavata* Grun.

G. olivaceum (Lyng.) Kütz.

G. olivaceum var. *calcarea* Cl.

G. parvulum Kütz.

G. sphaerophorum Ehr.

G. subclavatum (Grun.). Grun.

G. ventricosum Greg.

Gyrosigma acuminatum Kütz.

G. attenuatum (Kütz.) Rabh.

G. strigille W. Smith

Melosira granulata (Ehr.) Ralfs

M. granulata var. *angustissima* Müller

M. teres Brun

Meridion circulare (Grev.) Ag.

Navicula amphibola Cl.

N. anglica Ralfs

N. cari Ehr.

N. cincta (Ehr.) Ralfs

N. cryptocephala Kütz.

N. cryptocephala var. *veneta* (Kütz.) Grun.

N. cuspidata Kütz.

N. dicephala (Ehr.) W. Smith

N. exigua Greg. ex Grun.

N. gothlandica Grun.

N. graciloides A. Mayer

N. hungarica Grun.

N. hungarica var. *capitata* (Ehr.) Cl.

N. hungarica var. *linearis* Oestrup.

N. lanceolata (Ag.) Kütz.

N. laterostrata Hust.

N. oblonga Kütz.

N. pelliculosa (Bréb. ex Kütz.) Hilse

N. peltoensis Cl.

N. placentula var. *rostrata* A. Mayer

N. pseudoscutiformis Hust.

N. pupula Kütz.

N. pupula var. *capitata* Hust.

N. pupula var. *rectangularis* (Greg.) Grun.

N. radiosa Kütz.

N. rhyncocephala Kütz.

N. cf. schadei Krasske

N. seminulum Grun.

N. subtilissima Cl.

N. viridula Kütz.

N. vitabunda Hust.

N. vulpina Kütz.

Neidium affine (Ehr.) Pfitz.

N. dubium (Ehr.) Cl.

N. iridis (Ehr.) Cl.

N. iridis var. *ampliata* (Ehr.) Cl.

Nitzschia acicularis W. Smith

N. acuta Hantz.

N. amphibia Grun.

N. dissipata (Kütz.) Grun.

N. filiformis (W. Smith) Hust.

N. fonticola Grun.

N. frustulum (Kütz.) Grun.

N. gracilis Hantz.

N. hantzschiana Rabh.

N. kutzingiana Hilse

N. microcephala Grun.

N. ovalis Arnott

N. palea (Kütz.) W. Smith

N. paleacea Grun.

N. recta Hantz.

N. romana Grun.

N. sublinearis Hust.

Opephora martyi Hérib.

Pinnularia borealis Ehr.

P. interrupta W. Smith

P. maior (Kütz.) Rabh.

P. mesolepta (Ehr.) W. Smith

P. viridis (Nitz.) Ehr.

Rhoicosphenia curvata (Kütz.) Grun.

Rhopalodia gibba (Ehr.) O. Müll.

R. gibba var. *ventricosa* (Ehr.) Grun.

Stauroneis anceps Ehr.

S. anceps var. *hyalina* Brun & Peragal.

S. parvula Grun.

S. phoenicenteron Ehr.

S. smithii Grun.

Stephanodiscus astraea (Ehr.) Grun.

S. astraea var. *minutula* (Kütz.) Grun.

S. hantzschii Grun.

Surirella biseriata Bréb.

S. linearis W. Smith

S. tenera Greg.

Synedra acus Kütz.

S. acus var. *radians* (Kütz.) Hust.

S. capitata Ehr.

S. nana Meister

S. parasitica W. Smith

S. parasitica var. *subconstricta* Grun.

S. rumpens Kütz.

S. ulna (Nitz.) Ehr.

Tabellaria fenestrata (Lyngb.) Kütz.

T. flocculosa (Roth.) Kütz.

Of these, about 90% of the diatom fossils are of *Achnanthes exigua*, *A. lanceolata* var. *rostrata*, *Amphora ovalis* var. *pediculus*, *Asterionella formosa*, *Cyclotella comta*, *C. kutzingiana*, *Fragilaria brevistriata*, *F. construens*, *F. construens* var. *binodis*, *F. construens* var. *venter*, *F. crotonensis*, *F. pinnata*, *Rhopalodia gibba*, *R. gibba* var. *ventricosa*, *Stephanodiscus astraea* var. *minutula*, *S. hantzschii*, *Synedra acus* var. *radians* and *Tabellaria fenestrata*. Their stratigraphic percentage profiles are

given in Figure 9, and their estimated concentration diagram in Figure 10.

Fragilaria construens oscillates widely between less than 10% to more than 25%, from 700 to 320cm. Between 320 and 120cm it remains less variable within 15 to 25%. At 110cm this diatom has its lowest percentage (2.2%), increasing again towards the top of the core to percentages of more than 20%. On the other hand, the concentration profile shows three zones; the oldest one, beneath 430cm, has the highest concentrations; the middle zone, between 430 and 150cm, displays intermediate concentrations; and the upper one, from 150cm to the top, bears the lowest concentrations.

Fragilaria construens var. *venter* percentages have a stratigraphic distribution with four maxima, peaking at 570cm (65.4%), 330cm (62.5%), 160cm (49.9%), and 10cm (43.6%) respectively; and three minima in between, with values lower than 25% (as low as 16.2% at 500cm, and 9.7% at 110cm). However, the concentration profile, shows a threefold pattern; a basal zone with concentrations averaging more than 100 x 10^3 frustules per cm^3, below the 430cm level; a middle zone with values oscillating around 100 x 10^3 frustules/cm^3, from 430 to 280cm; and an upper one, from 280cm up, in which the concentration trends from 100 to 10 x 10^3 frustules/cm^3.

Fragilaria construens var. *binodis* has a clear bulge at the basal portion (below 600cm), and remains with

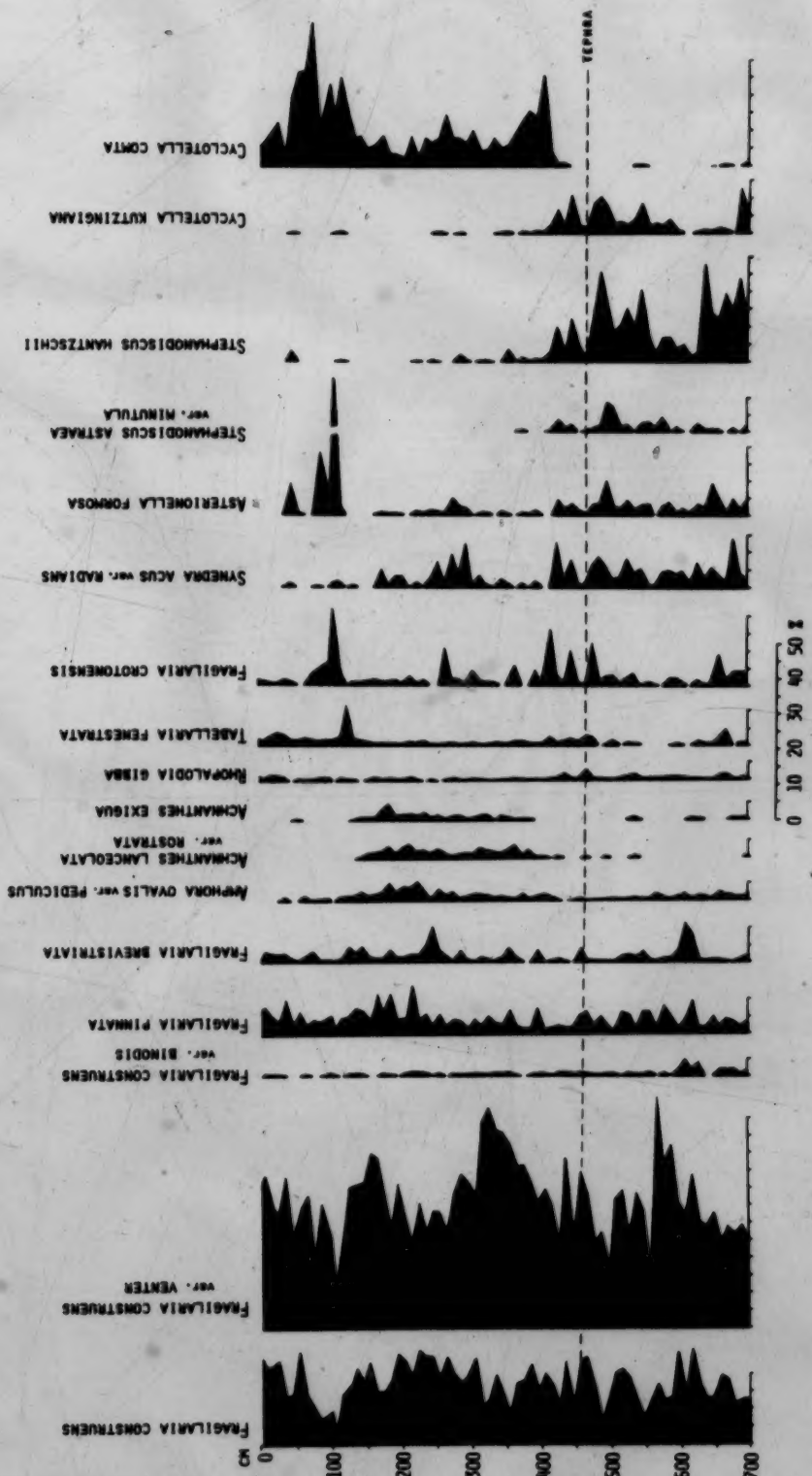

FIGURE 9 - CORE 1 DIATOM PERCENTAGE DIAGRAM.

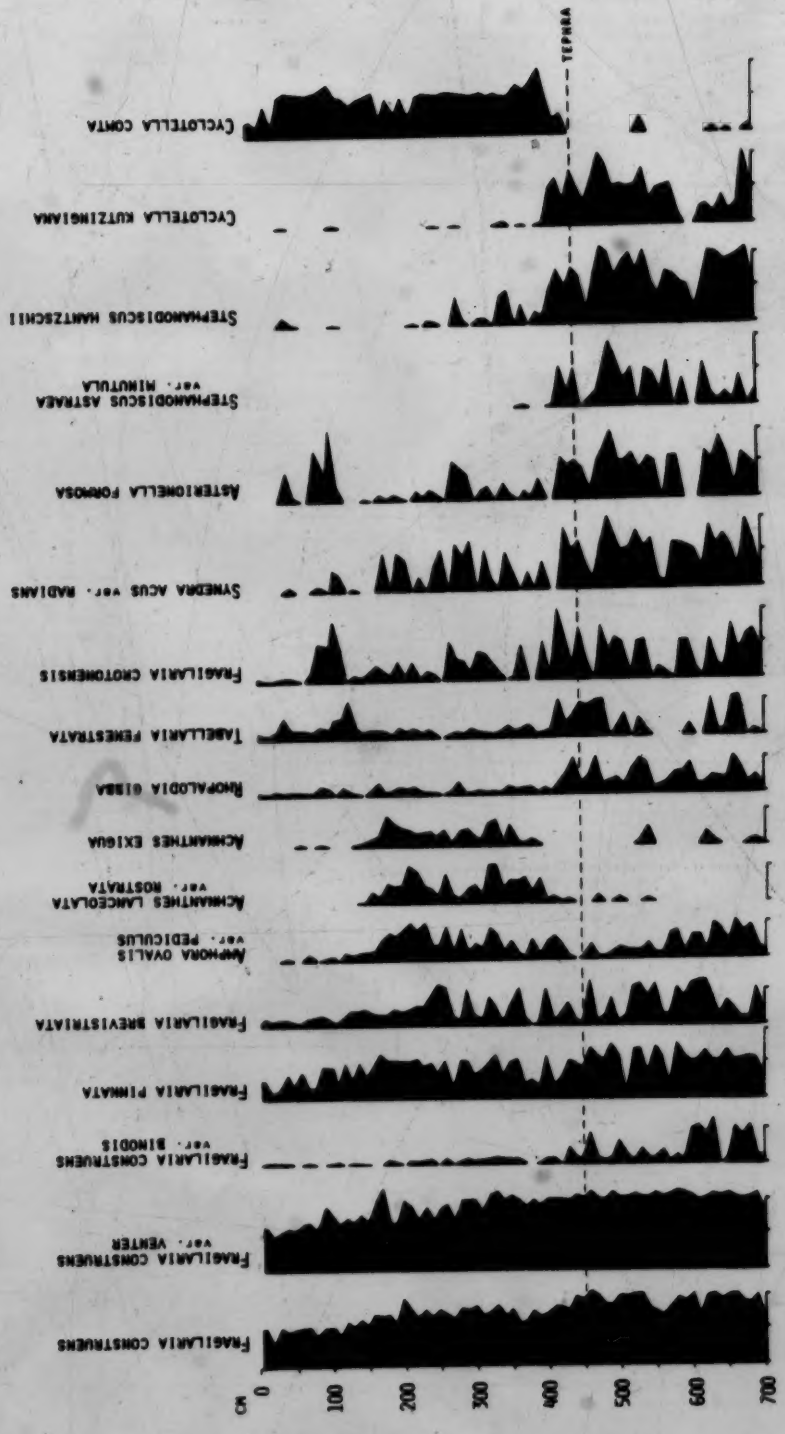

FIGURE 10 - CORE 1 DIATOM CONCENTRATION DIAGRAM.

percentages averaging less than 1% afterwards. A similar pattern is observed in the concentration spectrum.

Fragilaria pinnata has no marked trends in its stratigraphic profile, although a bulge with some percentages above 10% is apparent between 220 and 170cm, as well as two minima at 450-410cm and at 110cm. However, a threefold pattern is clear in the concentration diagram; from 430cm down the core the concentrations are higher; from 430 to 160cm they are intermediate; and in the top 160cm they are lower.

Fragilaria brevistriata presents two peaks where percentages are larger than 10%, at 610 and 250cm. After the latter the percentages decrease again to less than 5%, but seem to have a more continuous distribution. This pattern is also observed in the concentration profile, where a more continuous distribution at the basal area is also evident.

Amphora ovalis var. *pediculus* has two portions of its profile where the distribution is more continuous and prominent; a basal zone between 700 and 570cm, and another one between 420 and 120cm (where two peaks of more than 5% occur). After that, it becomes discontinuous, and finally disappears in the top 40cm. The same pattern holds in the concentration diagram.

Achnanthes lanceolata var. *rostrata* has a continuous distribution only between 410 and 150cm, and it is not found after that.

Achnanthes exigua has a similar distribution as *Achnanthes lanceolata* var. *rostrata*, with a significant and continuous zone restricted to the interval between 390 and 140cm, although this diatom has sporadic occurrences already below 550cm. After the 140cm level it is present only at the 90 and 60cm levels, with less than 1%.

Rhopalodia gibba (including the varieties *gibba* and *ventricosa*), is almost always present in the fossil record, but it seems to have been slightly more frequent below the 420cm level, and in the last 40cm. The concentration profile confirms its higher absolute values below 420cm.

Tabellaria fenestrata occurs discontinuously from the base to 480cm; and from there upwards it has a constant representation, becoming more prominent in the last 140cm of the core. If concentration peaks are considered, a threefold pattern is evident, with higher peaks below 420cm and above 130cm.

Fragilaria crotonensis displays a heterogeneously serrated profile. With the exception of a peak at 270cm, higher proportions tend to occur below 420cm and above 120cm, a pattern reproduced in the concentration diagram.

Synedra acus var. *radians* has a continuous and more significant representation below the 420cm level, and again between 310 and 250cm, disappearing in the last 40cm of the core. In the concentration spectrum, the above mentioned basal zone is very clear, but the middle bulge is not.

Asterionella formosa shows a continuous and significant representation below 430cm. It is weakly represented between 430 and 120cm, with the exception of a moderate peak at 280cm. Between 120 and 40cm (where it disappears) it has three pronounced peaks. This pattern is similarly seen in the concentration diagram.

Stephanodiscus astraea var. *minutula* is represented exclusively in the basal portion of the core, particularly below 430cm.

Stephanodiscus hantzschii has an ampler distribution in the core than the previous taxon; however, likewise it is clearly dominant in the oldest part, below 420cm. It is not represented in the last 40cm.

Cyclotella kutzingiana has in general lines a stratigraphic distribution similar to those of the previous two taxa.

Cyclotella comta shows a clear dominance in the upper half of the core, above the 420cm level, occurring only in four instances below this level, with very low percentages and concentrations. Within the upper 420cm, this diatom increases to more than 10% between 420-370cm, decreases to averages below 10% between 370 and 130cm, bulges again between 130 and 50cm, trending to diminish afterwards (a pattern also visible in the concentration diagram).

3.1.7 Chlorophyta

3.1.7.1 Desmidiaceae

These algae occur discontinuously throughout the core, but are definitely common in the basal portion below 430cm (Figure 11). The genera better represented are *Cosmarium*, and *Euastrum*.

3.1.7.2 Pediastrum

This microalga is observed only in three samples (Figure 11). It is common in the 650cm level, and rare in the 600 and 320cm levels.

3.1.7.3 Staurastrum

This genus has a descontinuous stratigraphic distribution (Figure 11), and it is generally rare; however, in the 630 and 600cm levels it is respectively abundant and common.

3.1.7.4 Tetraedron

This microfossil occurs abundantly in the basal portion of the core below 410cm (Figure 11); and discontinuously above it, being common only at the 240 and 105-110cm levels.

3.1.7.5 Zygnemataceae

Rare spores of these algae are only sporadically found at 540, 430, and 105cm (Figure 11).

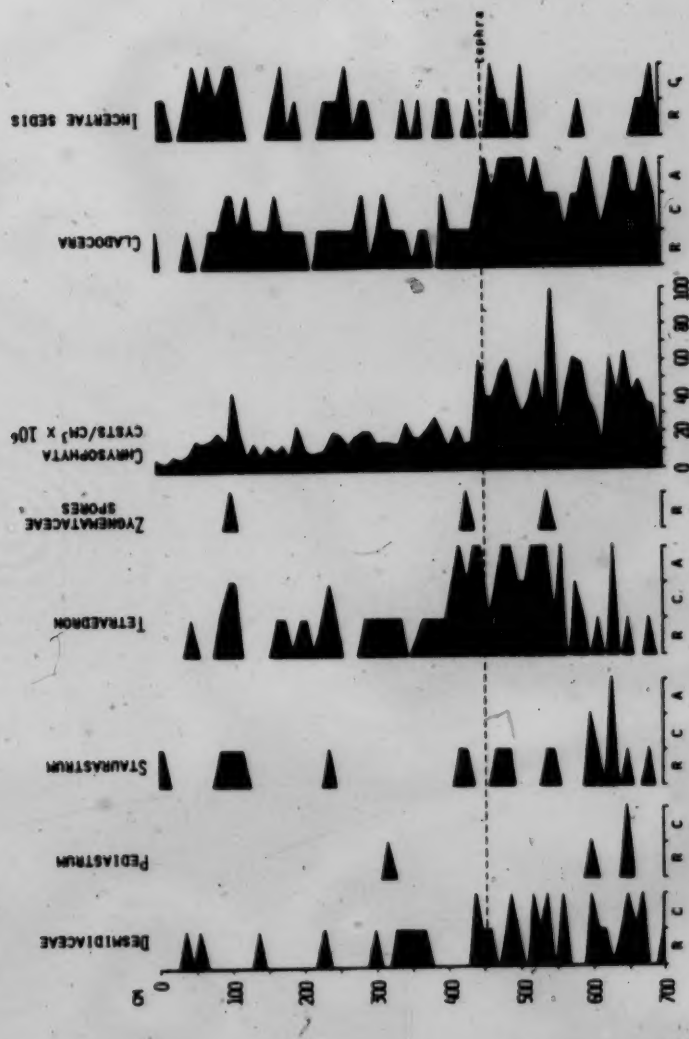

FIGURE 11 - CORE 1 CHLOROPHYTA, CHRYSOPHYTA, AND CLADOCERA. R = RARE, C = COMMON, A = ABUNDANT.

3.1.8 Chrysophyta

The cysts of these algae have a continuous presence throughout the core, but are conspicuously more abundant in the basal portion below 440cm (Figure 11), excepting an isolated peak at 110cm. An exceptionally high concentration occurs at the 550cm level. The cysts are generally very similar throughout, spherical, with a pore, and no ornamentation (cf. *Dinobryon*).

3.1.9 Cladocera

The record of these crustaceans shows an abundance of remains below 440cm level (Figure 11). Above it they tend to be rare (common only at 400, 320, 290, 170, 130, 110, and 105cm). The bulk of the Cladocera are of the genera *Bosmina* and *Daphnia*, although a precise identification remains to be done.

3.1.10 Incertae sedis

A variety of unknown microfossils are preserved throughout the core(Figure 11), many of them similar to remains illustrated by Van Geel (1978), but their significance is difficult to assess at present time.

3.2 Core 2

3.2.1 Core segments

Five drives were accomplished with the piston corer. The length of the respective core segments is given in Figure 12. The sediment is more compressible than that of Core 1 and, excepting for the third drive, the segments were shorter than 1m after extrusion. The last segment probably does not represent the base of the lake sediment, but it was not possible to penetrate further down with the piston corer manually operated. The upper 5cm were very fluid.

3.2.2 Stratigraphy

3.2.2.1 Sediment type

A schematic column of sediment types, including structures, is presented in Figure 12. As a whole, the 429cm of sediment recovered in Core 2 are predominantly fibrous organic mud. Plant macroremains are abundant in the basal portion beneath 345cm. Mollusc shells are visible near the base, particularly at the 420-410cm level. Volcanic ash pockets occur between 290 and 280cm. Wood pieces occur just above 150cm and below 100cm. A sandy zone extends from 265 to 215cm, and coarser sand and gravel are visible in the top 75cm. Although no marl is clearly observed, the sediment effervesces with cold 10% HCl below 375cm. The sediment has a sulfurous putrid odor throughout.

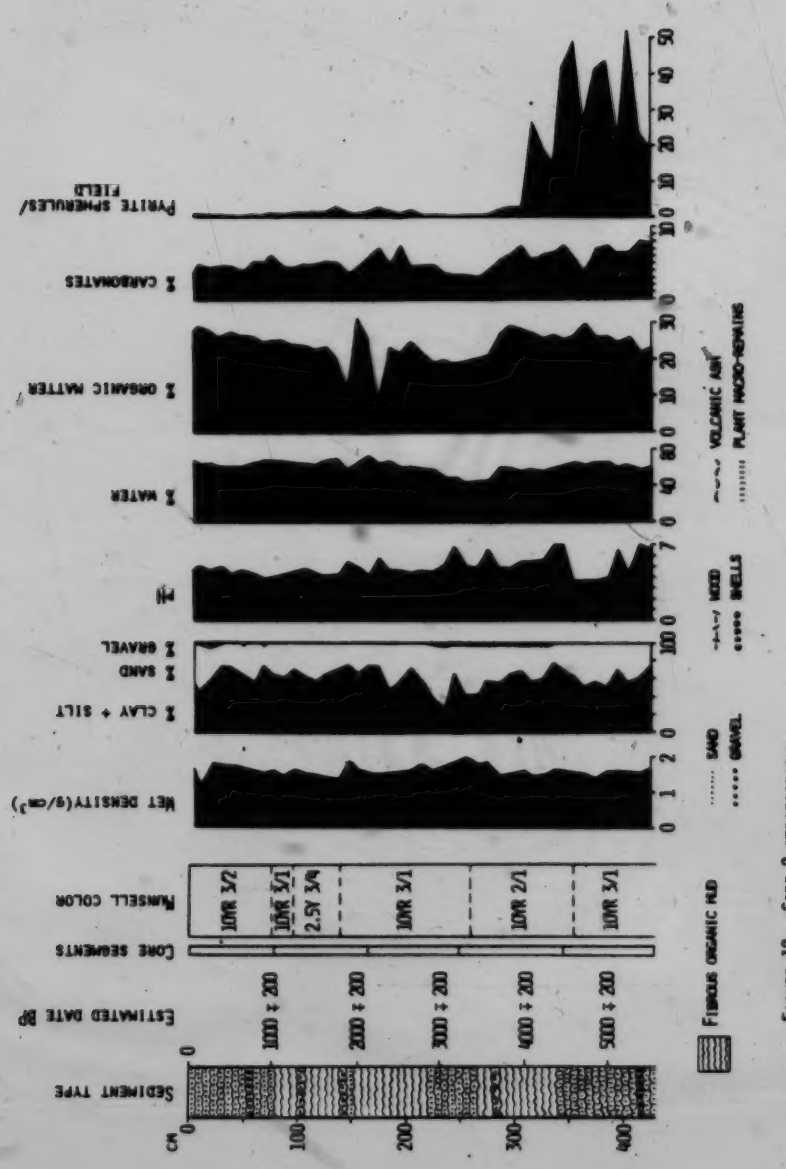

FIGURE 12 - CORE 2 STRATIGRAPHY.

3.2.2.2 Sand/gravel stereomicroscopy

In this core the coarser fractions are generally composed of single-grained particles (mainly quartz). Cleaner sand occurs at 420-410, 250-200, 160-140, and 5cm.

Volcanic ash shards are common below 280cm, but also occur between 110 and 90cm. The richest level was found between 290 and 280cm.

Sand size particles of coal occur throughout the core.

Charcoal fragments are common in the levels above 280cm, with a maximum between 220 and 210cm.

Molluscs occur below the 310cm level. They are generally bivalves of the genus *Pisidium*, but planorbids also occur between 350 and 340cm.

Remains of beetles are apparently more abundant in the upper 150cm.

Chitin cuticules occur throughout, more prominently between 200 and 110cm.

Plumatella statoblasts apparently occur throughout the core, but are more frequent below 230cm and above 170cm.

Daphnia hiphippia have the same stratigraphic distribution as the bryozoan statoblasts.

Potamogeton seeds are present below 230cm, and those of *Ranunculus* below 290cm.

Plant detritus is generally abundant. Mosses are present only above 40cm. Leaf cuticles are common between 350 and 110cm. Conifer needles are better represented below 280cm.

One occurrence of ostracods is registered at the 115cm level.

Small fish bones occur below 340cm.

Sand-sized diatoms of the genera *Stauroneis*, *Pinnularia*, *Surirella*, *Melosira*, *Synedra*, *Campylodiscus*, *Cymatopleura*, and, *Gyrosigma* are common throughout the core.

Characeae oogonia occur between 170 and 100cm.

Testaceous Rhizopoda are present in all samples, being abundant below 380cm, at 150cm, and between 80-70cm. The genera represented are *Difflugia* and *Centropyxis*. The former is generally more abundant, but below 390cm and at 150cm the the latter is also conspicuous.

Sand-sized gypsum crystals and drusy aggregates occur below the 350cm level.

3.2.2.3 Wet color

Figure 12 displays the stratigraphic changes in the predominant Munsell color of wet and relatively unoxidized sediment. The predominant colors are from very dark grey or black to very dark greyish brown, with the exception of a zone from 140 to 95cm, which is dark olive brown. The lower transition of this zone is mottled.

3.2.2.4 Density

The stratigraphic profile of wet density (Figure 12) delineates two bulges with values generally above 1.5g/cm^3, between 190 and 140cm, and 75-15cm. The rest of the core samples generally oscillate around 1.5g/cm^3.

3.2.2.5 Granulometry

As summarized in Figure 12, from the bottom to about 290cm the clay and silt fraction oscillate around 50-70%. From 290cm to 180cm it is more sandy and gravely. Between 180 and 30cm the sediment is even finer than at the bottom, to become coarser again in the upper 30cm.

3.2.2.6 pH

The basal part below 240cm yielded sediment pH values generally higher than 5, excepting a portion with pH <4 between 390 and 350cm (Figure 12). The samples above 240cm generally have the pH between 4 and 5.

3.2.2.7 Water content

The profile in Figure 12 shows that below 280cm the interstitial water averages 60%. In the sandy zone between 280 and 220cm it falls to less than 60%; and from there to the top water content is generally between 60 and 70%.

3.2.2.8 Organic matter

The O.M. percentage spectrum (Figure 12) delineates a basal zone, below 280cm, where the values generally exceed 25%; succeed by a zone of values lower than 25%, between 280 and 70cm; and another one in the upper 70cm where values again exceed 25%. The intermediate zone displays wide oscillations between 180 and 150cm, with two indentations of less than 7% and 12% respectively, and a peak of about 32% in between.

3.2.2.9 Carbonate

The CO_3^{--} concentrations, shown in Figure 12, have a zone of values generally higher than 3% below the 280cm level. From 280 to 200cm the carbonate content falls to a minimum of less than 2%. From 200cm to the top the values are generally lower than 2.5% (two peaks of more than 3% occur at 195 and 175cm).

3.2.2.10 Pyrite spherules

The number of pyrite spherules per field is much higher below the 310cm level, ranging from 15-52 spherules/field (Figure 12). The rest of the core has generally less than 3 spherules/field, with the lowest contents between 280-210cm and in the upper 100cm.

3.2.2.11 Radiocarbon dates

Six ^{14}C dates were obtained on a sequence of core segments, through the Geological Survey of Canada Radiocarbon Laboratory. All samples were pretreated with HCl. The results are given in Table 8.

3.2.3 Biogeochemistry

3.2.3.1 Carbon

The C concentrations presented in Figure 13 , being obtained as a constant function of the organic matter content, have a profile identical to the latter.

Table 8 - Core 2 radiocarbon dates

Depth (cm)	Lab. N°	Date BP ± 1σ	$^{o}/_{oo}$ $\delta^{13}C$	Corr. date BP
0-10	GSC-3276	5290 ± 60	-	-
71-76.5	GSC-3090	5200 ± 90	-24.9	5200 ± 90
159.5-164.5	GSC-3001	8400 ± 100	-24.8	8400 ± 100
270-275	GSC-3073	9470 ± 90	-25.3	9460 ± 90
338-342.5	GSC-3029	9730 ± 130	-27.4	9690 ± 130
425-429	GSC-2997	11,000 ± 120	-25.5	11,000 ± 120

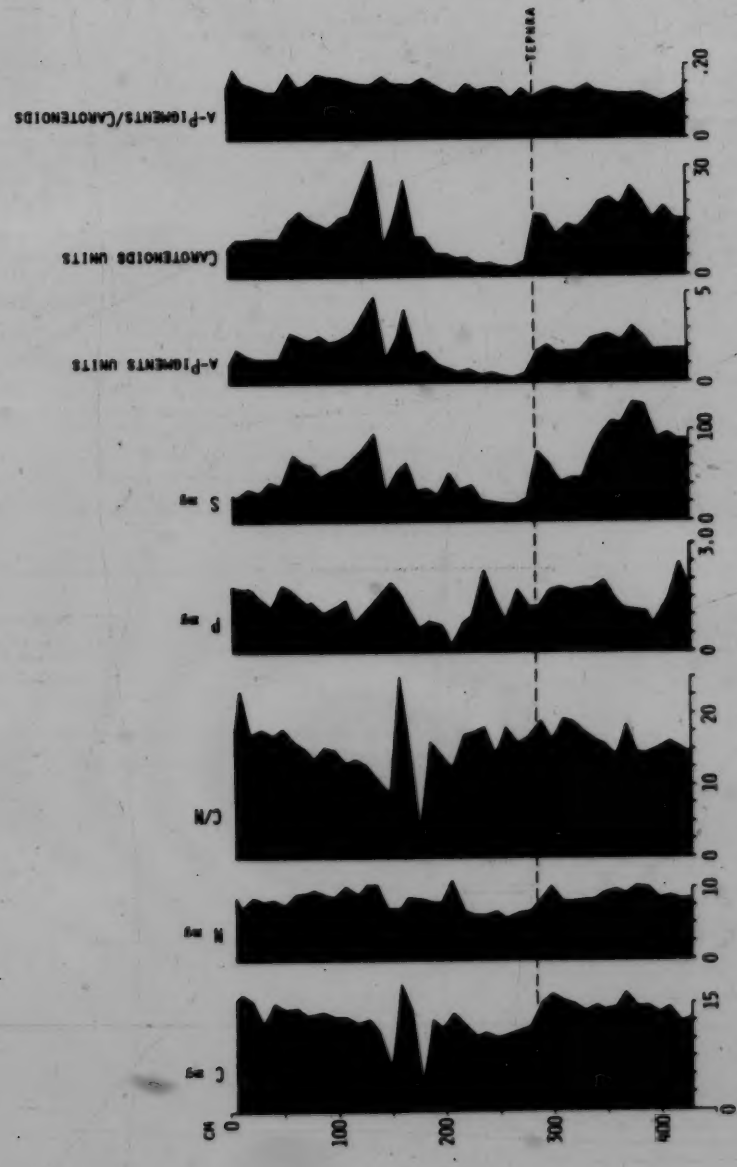

FIGURE 13 - CORE 2 BIOGEOCHEMISTRY (/g dry wt.).

3.2.3.2 Nitrogen

The N results, summarized in Figure 13, show a a trend similar to that of C below the 200cm level; that is, a zone of higher values (between 7.5 and 10.0 mg N/g dry wt.) beneath 280cm, followed by a minimum with less than 7.5 mg/g dry wt. (280-210cm). From 210 to the top values average again between 7.5 and 10.0 mg/g dry wt. In the upper 130cm it seems that the trend has been opposite to that of C, with values falling from around 10.0 mg/g dry wt. towards 7.5 mg N/g dry wt.

3.2.3.3 C:N ratio

The C:N ratio profile bulges at the basal portion below 210cm (Figure 13), to values of more than 15; then it oscillates widely between 210 and 150cm (from less than 5 to more than 25); and finally trends from 10 to around 20 in the upper 150cm of the core.

3.2.3.4 Total phosphorus

The P stratigraphic profile is less serrated in this core (Figure 13). Concentrations generally oscillate between 1 and 2 mg P/g dry wt. There is a wider zone of values lower than 1 mg/g dry wt. between 220 and 170cm. Only two peaks exceed 2 mg/g dry wt. (415 and 235cm).

3.2.3.5 Sulfur

The S stratigraphic spectrum, depicted in Figure 13, shows three different zones. The bottom one, from 280cm

down, has high values of sulfur, generally more than 40-60 mg S/g dry wt. In the next zone, from 280cm to 170cm, the values start from a drop to 20 mg/g dry wt. and trend towards more than 40 mg/g dry wt. The upper zone starts with a peak of more than 60 mg/g dry wt., oscillates back to 30 mg/g dry wt., and peaks again with about a 100 mg/g dry wt. at 140cm, to trend from there to the top to about 30 mg S/g dry wt.

3.2.3.6 a-Pigments

The three-zone pattern of the previous indicator is also clear in the a-pigment stratigraphy (Figure 13). A bulge at the basal portion with about 2 or more pigment units/g dry wt., followed by a drop to less than 1 unit and a trend to recuperate values of 2 units, to an upper zone that starts by wide oscillations to more than 4 units and trends back to around 1-2 units towards the top.

3.2.3.7 Carotenoids

The carotenoid profile is almost analogous to that of the a-pigments (Figure 13).

3.2.3.8 a-Pigments:Carotenoids ratio

A twofold stratigraphy can be described for this ratio, depicted in Figure 13. Below the 200cm level, values oscillate between 0.10 and 0.15; while, above that level values are as a rule grater than 0.15.

3.2.4 Metals

3.2.4.1 Sodium

Sodium has a fourfold stratigraphic distribution (Figure 14). The first zone, below 290cm, has values around 5-6 mg/g dry wt. The next one, from 290 to 140cm, bulges above these values, to a maximum of 17 mg/g dry wt. Between 140 and 60cm, again average 5-6 mg/g dry wt.; and in the top 60cm another bulge peaking at about 9 mg/g dry wt. is visible.

3.2.4.2 Potassium

The stratigraphic profile of K has a twofold pattern (Figure 14); with values generally around 11 mg/g dry wt. in the basal portion (below 290cm); and a wide bulge in the upper 290cm, which peaks between 170 and 130cm (16-18 mg/g dry wt.), returning gradually to the 10-11 mg/g dry wt. at the top.

3.2.4.3 Calcium

The general trend of Ca is to decrease from the base of the core upwards (Figure 14). Peaks of more than 6 mg/g dry wt. occur only below 240cm.

3.2.4.4 Magnesium

Magnesium does not display major stratigraphic changes (Figure 14). Below 290cm the values are more stable around 2.5 mg/g dry wt. Between 290 and 170cm values are more variable; and above 170cm the concentrations stabilize at

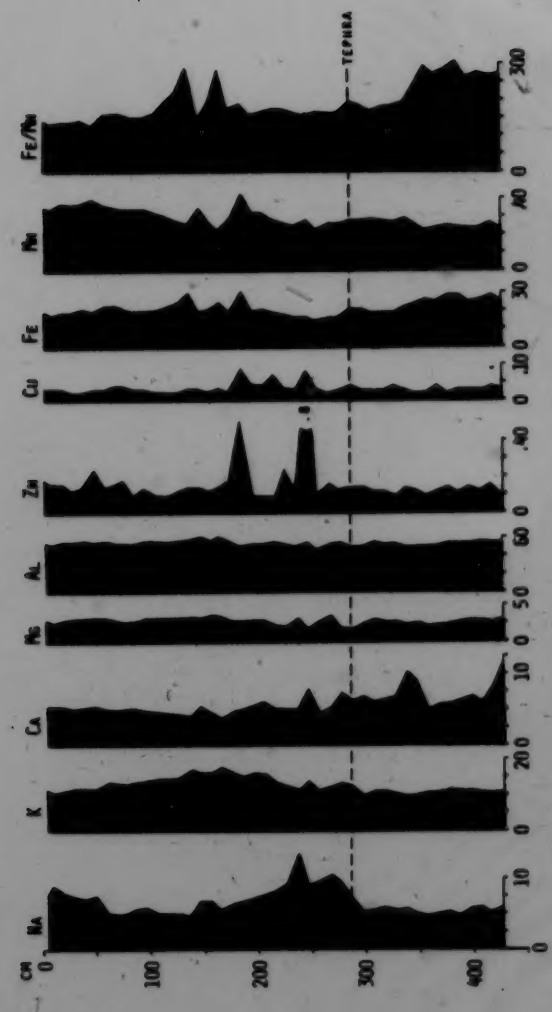

FIGURE 14 - CORE 2 METALS (mg/g dry wt.).

slightly higher values (more than 3 mg/g dry wt.).

3.2.4.5 Aluminum

Aluminum has a trend comparable of that of Mg (Figure 14). Below 170cm, values tend to fall between 50 and 55 mg/g dry wt. In the upper 170cm, this metal has concentrations somewhat higher (generally above 55 mg Al/g dry wt.).

3.2.4.6 Zinc

Below 80cm the Zn profile has generally values between 0.10 and 0.15 mg/g dry wt., interrupted by three marked peaks between 250 and 170cm (Figure 14). In the upper 80cm Zn concentrations are generally higher than 0.15 mg/g dry wt.

3.2.4.7 Copper

Copper concentrations are generally around 0.03 mg/g dry wt. throughout the core (Figure 14), with the exception of a middle-section zone coincidental with that of Zn, between 250 and 170cm, where three peaks exceed 0.07 mg/g dry wt.

3.2.4.8 Iron

As shown in Figure 14, Fe concentrations fall between 20 and 30 mg/g dry wt. below 330cm. From 330 to 280cm they stabilize around 20 mg/g dry wt. From 280 to 210cm the lowest values of the Fe profile are attained (10-20 mg/g dry wt.). An area of higher variability, and peaks up to 30 mg/g dry wt., extends from 210 to 110cm; followed by an upper

zone of stable values around 20 mg/g dry wt.

3.2.4.9 Manganese

The Mn spectrum shown in Figure 14, can be described summarily in three zones. From the bottom to 210cm, values oscillate between 0.20 and 0.30 mg/g dry wt.; then oscillate widely with two peaks of more than 0.30 mg/g dry wt., between 210 and 110cm; finally assuming values higher than 0.30 mg/g dry wt. in the last 110cm.

3.2.4.10 Fe:Mn ratio

The Fe:Mn ratio follows very closely the iron profile (Figure 14). It displays a basal maximum below 330cm, with values between 250 and 300. From 330cm upwards, a gradual trend from values around 200 to values between 100-150, is interrupted by two peaks of more than 250, between 170 and 130cm.

3.2.5 Pollen and spores

The following 39 palynomorph taxa were identified in Core 2:

Abies
Alnus
Anemone canadensis
Arceuthobium americanum
Artemisia
Betula
Bothrychium

Bryophyta

Caryophyllaceae

Chenopodiaceae/Amaranthaceae

Compositae (Tubuliflorae)

Cyperaceae

Ephedraceae

Ericaceae

Eriogonum

Fragaria vesca

Isoetaceae

Juniperus

Larix/Pseudotsuga

Lycopodiaceae

Monolete spores

Myricaceae/Corylaceae

Myriophyllum

Onagraceae

Picea

Pinus (diploxylon)

Poaceae (=Gramineae)

Polypodiaceae

Populus

Potamogeton

Ranunculus

Salix

Sphagnaceae

Thalictrum

Triglochin

Trilete spores

Tsuga heterophylla

Tsuga mertensiana

Umbelliferae

As in the first core, only *Pinus*, *Picea*, *Abies*, *Alnus*, *Betula*, and Cyperaceae pollen exceed 2% among the terrestrials, while only *Myriophyllum* is represented with more than 2% among the aquatics. Their stratigraphic profiles are summarized in Figure 15 .

The arboreal pollen (AP) is also generally more than 90-95% throughout this core; however, the non-arboreal pollen (NAP) is slightly more pronounced below 260cm. This high of NAP is more clearly seen in Figure 16 , below the 270cm level. The AP is definitely dominated by pine (50-85%), and spruce (10-20%). In the basal portion alder is also important.

Below 140cm pine oscillates between 60 and 80%, with the exception of three levels (290-320cm) where it falls between 50 and 60%. In the upper 140cm pine averages more than 80%.

The spruce pollen percentage profile displays two zones. Below 140cm the values oscillate between 10 and 20%, whereas above 140cm level percentages oscillate around 10%.

Fir does not change significantly, although percentages higher than 3% are more common in the upper half of the core. The concentration diagram also suggests this tendency

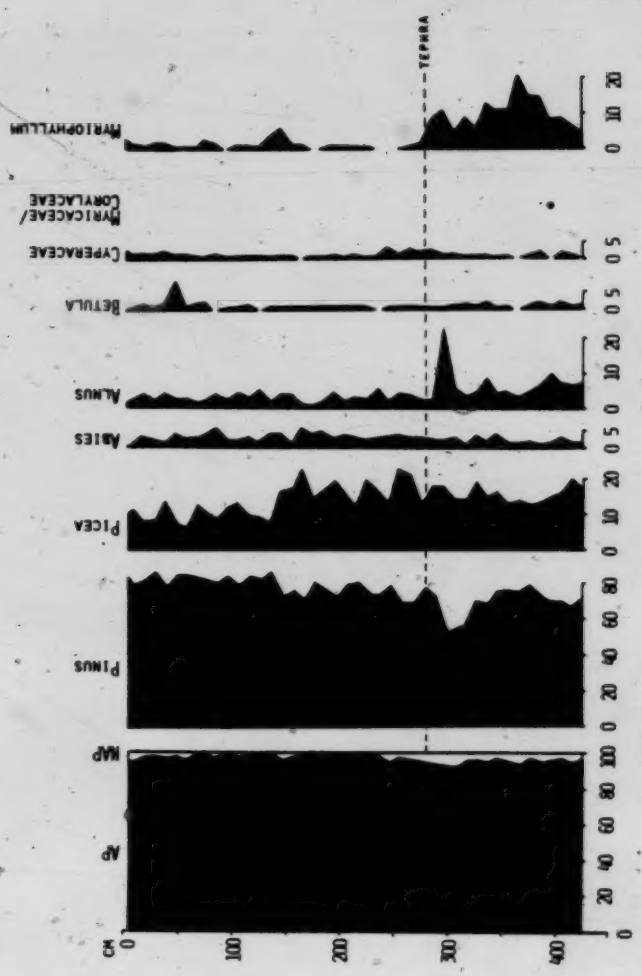

FIGURE 15 - CORE 2 PERCENTAGE POLLEN DIAGRAM.

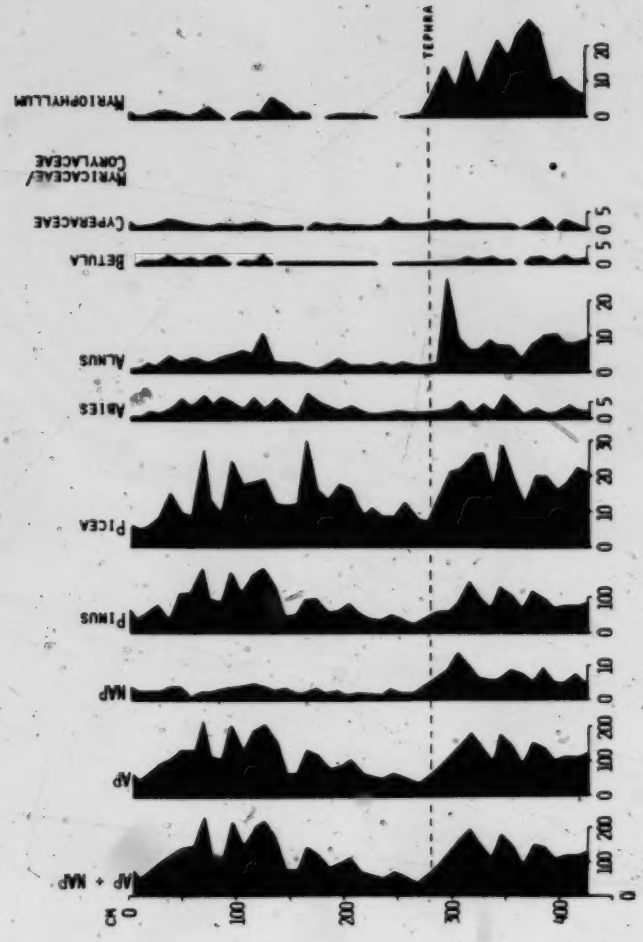

FIGURE 16 - CORE 2 CONCENTRATION POLLEN DIAGRAM (POLLEN/cm^3 x 10^3).

to higher *Abies* in the upper half.

Alder is proportionally and absolutely more abundant in the basal 290cm. A marked peak of *Alnus* occurs at the 295cm level.

Betula pollen is slightly higher in the levels below 310cm, and above 80cm (peaking at 50cm).

Sedges seem to be more continuously distributed and slightly better represented between 310 and 240cm.

In this core Myricaceae/Corylaceae are present only between 400 and 390cm.

The only prominent aquatic pollen, *Myriophyllum*, is almost absent in the interval between 270 and 170cm; and is definitely more abundant in the oldest portion of the core, below 280cm. A marked peak occurs at 365cm.

A generalization of the concentration pollen diagram profiles indicates a trend towards higher concentrations from the bottom to 320-310cm; followed by a drop to a minimum around 270-260cm; succeeded by a gradual trend to a maximum bulge between 140 and 60cm; and a final decrease to the present. The uppermost 5cm were not analyzed for pollen and, therefore, it is not known if the increase observed in Core 1 is repeated here.

The average of taxa per level is 14, with a range of 10-18; and the percentage of indeterminable palynomorphs averaged 1.7%. Pre-Quaternary palynomorphs are never present in the samples.

3.2.6 Diatoms

A total of 162 diatom taxa were identified to the level of variety in Core 2, consisting of (varietal names are omitted when identical to the specific names):

Achnanthes clevei Grun.

A. clevei var. *rostrata* Hust.

A. conspicua A. Mayer

A. exigua Grun.

A. hauckiana Grun.

A. lanceolata (Bréb.) Grun.

A. lanceolata var. *elliptica* Cl.

A. lanceolata var. *rostrata* Hust.

A. marginatula Grun.

A. minutissima Kütz.

A. peragalli var. *fossilis* Temp. & Perag.

Amphipleura pellucida Kütz.

Amphiprora ornata Bailey

Amphora ovalis Kütz.

A. ovalis var. *lybica* (Ehr.) Cl.

A. ovalis var. *pediculus* Kütz.

A. veneta Kütz.

Asterionella formosa Hass.

Caloneis bacillum (Grun.) Mereschk.

C. shumanniana var. *biconstricta* Grun.

C. silicula alpina Cl.

C. silicula var. *truncatula* Grun.

C. ventricosa var. *minuta* (Grun) Patr.

Ceratoneis arcus Kütz.

Cocconeis diminuta Pant.

C. disculus Schum.

C. palcentula Ehr.

C. placentula var. *euglypta* (Ehr.) Cl.

Cyclotella comta (Ehr.) Kütz.

C. kutzingiana Thwaites

C. meneghiniana Kütz.

Cymatopleura solea (Bréb.) W. Smith

C. solea var. *regula* (Ehr.) Grun.

Cymbella cistula (Hempr.) Grun.

C. cuspidata Kütz.

C. ehrenbergii Kütz.

C. heteropleura (Ehr.) Kütz.

C. microcephala Grun.

C. muelleri Hust.

C. naviculiformis Auerwald

C. prostrata (Berkeley) Cl.

C. sinuata Greg.

C. thumensis (Mayer) Hust.

C. turgida (Greg.) Cl.

C. ventricosa Kütz.

Diatoma elongatum Agardh.

Diploneis oculata (Bréb.) Cl.

D. pseudovalis Hust.

Epithemia sorex Kütz.

E. turgida (Ehr.) Kütz.

E. turgida var. *granulata* (Ehr.) Grun.

E. zebra (Ehr.) Kütz.

E. zebra var. *porcellus* (Kütz.) Grun.

Fragilaria brevistriata Grun.

F. capucina (Ehr.) Grun.

F. capucina var. *mesolepta* Rabh.) Grun.

F. construens (Ehr.) Grun.

F. construens var. *binodis* (Ehr.) Grun.

F. construens var. *subsalina* Hust.

F. construens var. *venter* (Ehr.) Grun.

F. crotonensis Kitton

F. leptostauron var. *dubia* (Grun.) Hust.

F. pinnata Ehr.

F. pinnata var. *interscedens* (Grun.) Hust.

F. vaucheriae (Kütz.) Peters.

F. virescens Ralfs.

Gomphonema acuminatum Ehr.

G. acuminatum var. *brebissonii* (Kütz.) Cl.

G. acuminatum var. *coronata* (Ehr.) W. Smith

G. acuminatum var. *pusilla* Grun.

G. angustatum (Kütz.) Rabh.

G. constrictum Ehr.

G. constrictum var. *capitata* (Ehr.) Cl.

G. gracile Ehr.

G. intricatum Kütz.

G. longiceps var. *subclavata* Grun.

G. olivaceum (Lyngb.) Kütz.

G. olivaceum var. *calcarea* Cl.

G. parvulum Kütz.

G. subclavatum (Grun.) Grun.

G. ventricosum Greg.

Gyrosigma acuminatum Ehr.

G. attenuatum (Kütz.) Rabh.

G. strigille W. Smith

Melosira granulata (Ehr.) Ralfs

M. teres Brun

Meridion circulare Agardh.

Navicula amphibola Cl.

N. anglica Ralfs.

N. cari Ehr.

N. cryptocephala Kütz.

N. cryptocephala var. *veneta* (Kütz.) Grun.

N. cuspidata Kütz.

N. dicephala (Ehr.) W. Smith

N. exigua Greg. ex Grun.

N. gothlandica Grun.

N. gracilpides A. Mayer

N. hungarica Grun.

N. hungarica var. *capitata* (Ehr.) Cl.

N. hungarica var. *linearis* Oestrup.

N. lanceolata (Ag.) Kütz.

N. minima Grun..

N. oblonga Kütz.

N. peltoensis Cl.

N. placentula var. *rostrata* A. Mayer

N. pseudoscutiformis Hust.

N. pupula Kütz.

N. pupula var. *capitata* Hust.

N. pupula var. *rectangularis* (Greg.) Grun.

N. radiosa Kütz.

N. rhyncocephala Kütz.

N. cf. *schadei* Krasske

N. seminulum Grun.

N. subtilissima Cl.

N. viridula Kütz.

N. vulpina Kütz.

Neidium affine (Ehr.) Pfitz.

N. dubium (Ehr.) Cl.

N. iridis (Ehr.) Cl.

N. iridis var. *ampliata* (Ehr.) Cl.

Nitzschia acicularis W. Smith

N. amphibia Grun.

N. dissipata Grun.

N. fonticola Grun.

N. frustulum (Kütz.) Grun.

N. kutzingiana Hilse

N. microcephala Grun.

N. ovalis Arnott.

N. palea (Kütz.) W. Smith

N. paleacea Grun.

N. recta Hantz.

N. romana Grun.

Opephora martyi Hérib.

Pinnularia borealis Ehr.

P. gibba Ehr.

P. interrupta W. Smith

P. maior (Kütz.) Cl.

P. mesolepta (Ehr.) W. Smith

P. viridis (Nitz.) Ehr.

Rhopalodia gibba (Ehr.) O. Müll.

R. gibba var. *ventricosa* (Ehr.) Grun.

Stauroneis anceps Ehr.

S. anceps var. *hyalina* Brun & Peragallo

S. parvula Grun.

S. phoenicenteron Ehr.

S. smithii Grun.

Stephanodiscus astraea var. *minutula* (Kütz.) Grun.

S. hantzschii Grun.

Surirella biseriata Bréb.

S. linearis W. Smith

S. robusta Ehr.

Synedra acus Kütz.

S. acus var. *radians* (Kütz.) Hust.

S. capitata Ehr.

S. nana Meister

S. parasitica W. Smith

S. parasitica var. *subconstricta* Grun.

S. rumpens Kütz.

S. rumpens var. *fragilarioides* Grun.

S. ulna (Nitz.) Ehr.

Tabellaria fenestrata (Lyngb.) Kütz.

T. flocculosa (Roth.) Kütz.

Of these, as in the first core, about 90% of the fossil diatoms are of *Achnanthes exigua*, *A. lanceolata* var. *rostrata*, *Amphona ovalis* var. *pediculus*, *Asterionella formosa*, *Cyclotella comta*, *C. kutzingiana*, *Fragilaria construens*, *F. construens* var. *binodis*, *F. construens* var. *venter*, *F. crotonensis*, *F. pinnata*, *Rhopalodia gibba*, *R. gibba* var. *ventricosa*, *Stephanodiscus astraea* var. *minutula*, *S. hantzschii*, *Synedra acus* var. *radians*, and *Tabellaria fenestrata*. Their stratigraphic percentage profiles are given in Figure 17 , and their estimated concentration diagram in Figure 18.

Fragilaria construens goes from about 10% at the bottom levels to percentages of 20-30% between 370 and 280cm. From 280cm upwards it oscillates generally between 10 and 20%. The concentration profile, however, shows four alternating zones, starting with higher concentrations in the basal portion below 280cm, followed by a low (280-190cm), another high (190-60cm, except 150cm), and a more recent low in the last 60cm.

Fragilaria construens var. *venter* percentages delineate a serrated profile of high percentages throughout the core (only three levels had less than 40%), but only in the bottom 30cm percentages surpass 70% (concentrations are the

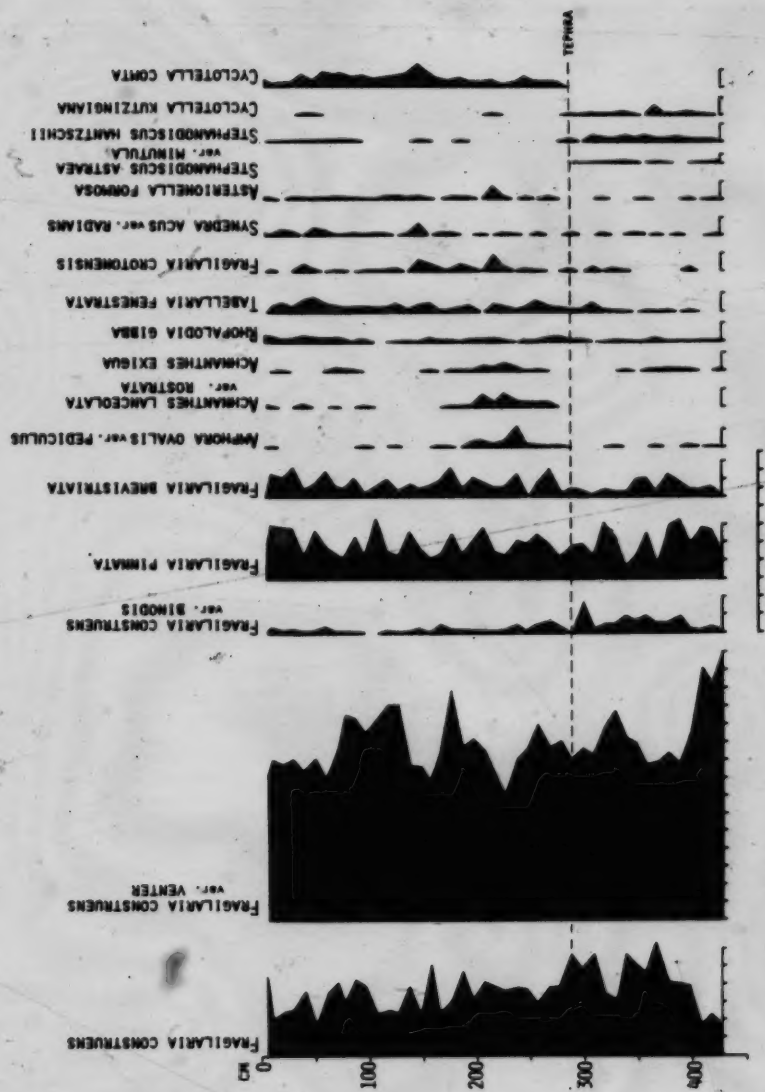

FIGURE 17 - CORE 2 DIATOM PERCENTAGE DIAGRAM.

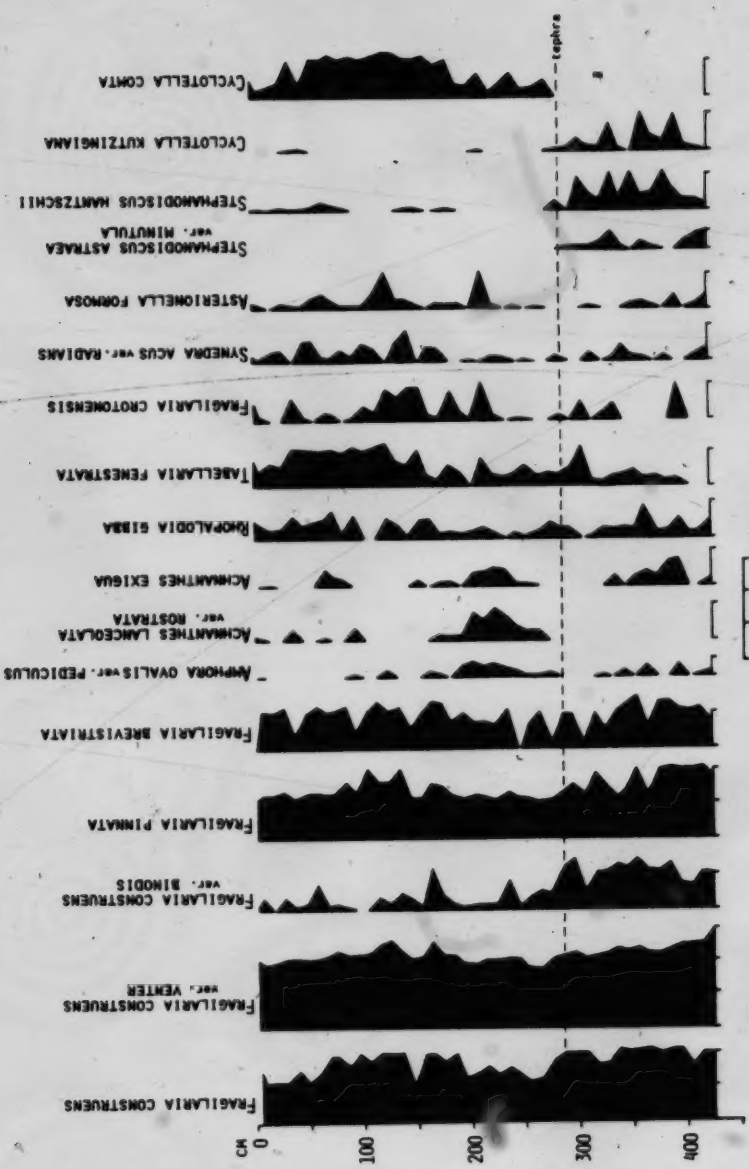

FIGURE 18 - CORE 2 DIATOM CONCENTRATION.

highest too). In the upper 60cm percentages oscillate around 40-45%. A fourfold zonation analogous to that of *F. construens* is also noticed in the concentration diagram.

Fragilaria construens var. *binodis* displays higher percentages and concentrations in the basal half.

Fragilaria pinnata percentages oscillate almost symmetrically between 5 and 15% throughout the core. However, the concentration profile can be better described as an alternation of four zones in the same fashion of *F. construens*, and *F. construens* var. *venter*, starting by a basal high, a depression, another high, and a final more recent low.

Fragilaria brevistriata has a more continuous distribution, and a higher percentage average in the upper half of the core. In the concentration profile this is also evident, but here this diatom has some significantly high values also in the basal portion below 340cm.

Amphora ovalis var. *pediculus* has a continuous distribution and its maximum proportions and concentrations in the mid section (280-190cm). It disappears from the record in the upper 90cm.

Achnanthes lanceolata var. *rostrata* starts its record at the 280-270cm level, and has its optimum in the mid section (270-170cm).

Achnanthes exigua has significant appearances at 400-350cm, 250-200cm, and 90-70cm, with its maximum proportions in the mid section.

Rhopalodia gibba (including the varieties *gibba* and *ventricosa*, is almost always part of the fossil record, with proportions slightly enhanced in the upper 70cm.

Tabellaria fenestrata trends towards better representation in the upper portion of the core, the concentration optimum occurring between 130 and 40cm.

Fragilaria crotonensis has a discontinuous record, particularly at the base, and seems to have been better represented in the upper mid-section (220-120cm).

Synedra acus var. *radians* is more abundant in the upper 170cm, which is better seen in the concentration diagram.

Asterionella formosa is more continuously distributed in the upper half of the core, accompanied by higher concentrations above the 220cm level.

Stephanodiscus astraea var. *minutula* is weakly and exclusively represented below the volcanic ash level (290-280cm).

Stephanodiscus hantzschii appears continuously only in the basal and upper portions of the core, being significantly more abundant in the former (below 290-280cm).

Cyclotella kutzingiana , as the previous taxa, has a preferential distribution in the basal part below the tephra level (290-280cm).

Cyclotella comta occurs exclusively above the main volcanic ash level (290-280), and shows a clear optimum between 190 and 60cm.

3.2.7 Chlorophyta

3.2.7.1 Desmidiaceae

These algae occur continuously only in the basal portion of the core below 320cm, being common at 405, 345, and 325cm (Figure 19) . They are absent from the mid section. The better represented genera are *Cosmarium*, and *Euastrum*.

3.2.7.2 Pediastrum

This microalga is present only in seven samples where it is rare (Figure 19).

3.2.7.3 Staurastrum

This genus has a very discontinuous distribution in Core 2, being rare throughout ((Figure 19).

3.2.7.4 Tetraedron

This microfossil occurs abundantly in the basal portion of the core below 310cm (Figure 19); and has only three rare appearances above the tephra horizon (290-280cm).

3.2.7.5 Zygnemataceae

Rare spores of these algae are present only at the 335 and 185cm levels (Figure 19).

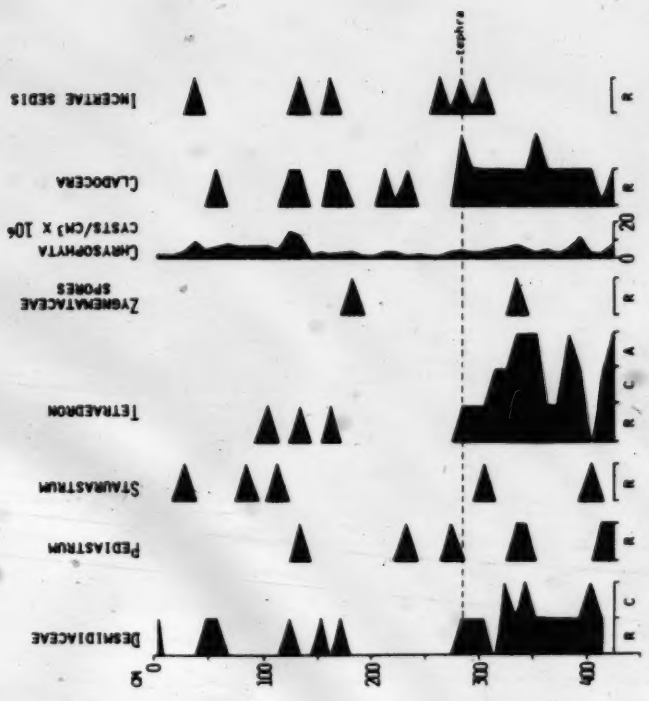

FIGURE 19 - CORE 2 CHLOROPHYTA, CHRYSOPHYTA, AND CLADOCERA. R = RARE, C = COMMON, A = ABUNDANT.

3.2.8 Chrysophyta

The cysts of these algae have a continuous presence throughout the core, but are more abundant below 280cm, and particularly between 140 and 40cm (Figure 19). The cysts are generally similar to those described for Core 1, that is, spherical, with a simple pore and no ornamentation (cf. *Dinobryon*).

3.2.9 Cladocera

The record of these crustaceans (Figure 19) shows a continuous distribution only in the basal portion (below 280cm). In this zone there are two instances when they were common (355 and 285cm). Above the tephra horizon (290-280cm) they are rare, and appear only in seven samples. The majority of the Cladocera are of the genera *Bosmina* and *Daphnia*.

3.2.10 Incertae sedis

Likewise in Core 1, although rarer, a variety of unknown microfossils are preserved throughout the core (Figure 19), many of them similar to remains illustrated by Van Geel (1978); however, its significance is indeterminable at present time.

3.3 Surface samples

3.3.1 Geochemistry

The elemental analyses produced the data presented in Table 9.

3.3.2 Pollen and spores

A summary of pollen and spores surface countings is given in Table 10.

3.3.3 Diatoms

More than 40 diatom taxa were identified in a surficial bottom sample taken under 4m of water; however, about 90% of the specimens corresponded to:

Achnanthes lanceolata var. *elliptica* Cl. (0.8%)

Amphora ovalis var. *pediculus* Kütz. (1.4%)

Cyclotella comta (Ehr.) Kütz. (2.5%)

Diploneis puella (Shum.) Cl. (2.9%)

Fragilaria brevistriata Grun. (10.8%)

F. construens (Ehr.) Grun. (33.2%)

F. construens var. *binodis* (Ehr.) Grun. (0.6%)

F. construens var. *venter* (Ehr.) Grun. (27.1%)

F. crotonensis Kitton (0.6%)

F. leptostauron (Ehr.) Hust. (0.6%)

F. pinnata Ehr. (4.8%)

Gyrosigma acuminatum Kütz. (2.2%)

Navicula cryptocephala Kütz. (0.8%)

Table 9 - Watershed geochemistry (mg/g dry wt.)

Element	N slope shale	N slope soil	S slope sandstone	S slope till
P	3.81	2.71	1.97	1.08
S	6.62	2.49	5.20	1.58
Na	4.60	4.70	14.30	10.00
K	24.60	20.00	16.20	22.00
Ca	0.10	0.03	0.80	1.90
Mg	6.40	4.20	8.40	6.30
Al	66.90	65.80	65.30	64.70
Zn	0.14	0.08	0.13	0.11
Cu	0.06	0.04	0.06	0.04
Fe	26.40	25.70	26.40	24.30
Mn	0.13	0.05	0.41	0.62

Table 10 - Percentage of surface pollen/spores

	Lake bottom (11m)	N slope	S slope	E Mire
Pinus	82.4	91.6	69.2	70.0
Picea	5.5	3.9	11.7	6.3
Abies	2.0	0.5	2.0	2.8
Alnus	4.5	2.0	5.8	3.6
Betula	0.5	-	3.8	0.9
Cyperaceae	0.8	-	0.4	11.7
Other AP	1.1	0.2	1.3	0.8
Other NAP	3.2	1.8	5.8	3.9
Myriophyllum	0.3	-	-	-

Rhopalodia gibba (Ehr.) O. Müll. (0.3%)

Synedra acus var. *radians* (Kütz.) Hust. (0.3%)

Tabellaria fenestrata (Lyngb.) Kütz. (0.5%).

4. DISCUSSION AND CONCLUSION

4.1 Chronology

The plotting of the available radiocarbon dates (Tables 7 and 8) against the respective sample depths, shown in Figure 20, can be described by the following simple linear regression models:

Core 1 sample date BP = 8.12 x sample depth + 2894, r=0.93; and

Core 2 sample date BP = 14.33 x sample depth + 5116, r=0.96;

where both correlation coefficients are significant at the 0.001 significance level.

In view of this, there are two hypotheses to consider:

a) The radiocarbon dates are correct; or

b) The dates are too old, by aproximately 2900 radiocarbon years in Core 1, and 5100 in Core 2.

If the first hypothesis is correct, than it is necessary to admit that: there has been no deposition in both coring sites for the last 2900 and 5100 years, respectively, or that only the top radiocarbon dates are too old; the main volcanic ash horizons (at 457-455cm in Core 1, and 285cm in Core 2) are not contemporaneous; the stratigraphic similarities between the two cores are purely coincidental (e.g. Ca, Mg, Al, S, Carbonates, *Fragilaria construens* var. *binodis*, *Tabellaria fenestrata*, *Synedra acus*

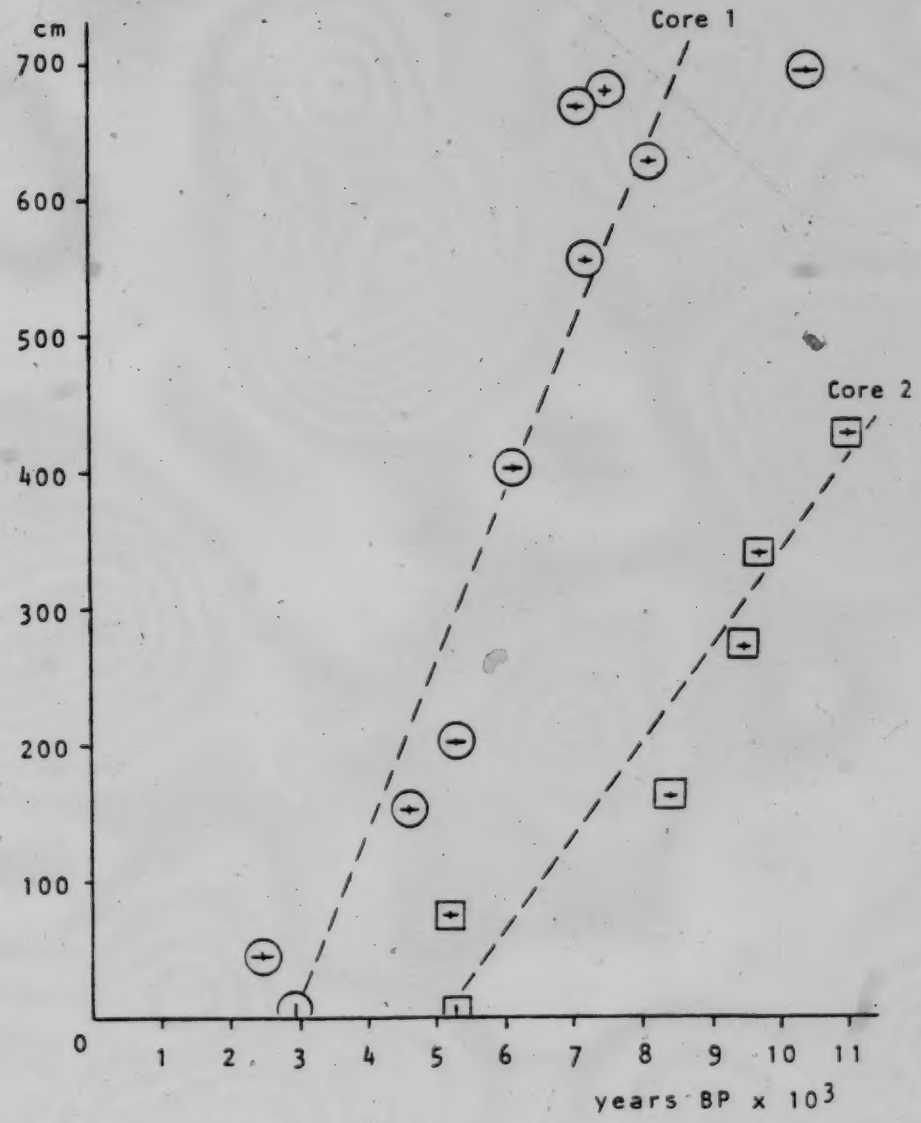

Figure 20 - Radiocarbon dates versus depth.

var. *radians*, *Asterionella formosa*, *Stephanodiscus astraea* var. *minutula*, *S. hantzschii*, *Cyclotella kutzingiana*, *C. comta*, *Pinus*, *Alnus*, and *Myriophyllum*, are correlated in the same way with core depth); and the vegetation of the watershed remained basically unchanged for the last 11,000 years. All of those possibilities are very unlikely. Actually, there is no way of explaining the lack of sediment deposition or active bottom erosion in a stratified lake, particularly at the site of the deepest core, or a reason for radiocarbon error exclusively at the top. The tephras are very similar in appearance under the stereomicroscope and at the bulk chemistry level; and other regional pollen studies indicate the prevalence of a much more open vegetation before 10,000 BP, and lower proportions of pine in relation to higher spruce before 9000 BP (Lichti-Federovich, 1970; Schweger et al., in press; Ritchie, 1976, 1980). Therefore, the second hypothesis is preferred.

Due to differential compression (natural and during coring), as well as other depositional differences between cores, a slight correction seems necessary. If the volcanic ash, diatom, pollen, and geochemistry stratigraphy of both cores are matched, a slope of 12.98 would be more appropriate to estimate the dates of samples from Core 2. A deviation of at least ±200 years should also be allowed. Thus, the following tentative equations will be used in the subsequent discussion:

Core 1 sample date BP = 8.12 x sample depth ±200; and

Core 2 sample date BP = 12.98 x sample depth ±200.

In this case, the bottom of the cores would be about 6000±200 BP; and the more conspicuous volcanic ash about 3800±200 BP, which falls within the the age of the St. Helens Y tephra set (Mullineaux et al., 1975). The presence of a mineral tentatively identified as cummingtonite (M. Bombin, personal communication), is another piece of information in favor of a St. Helens Y set identity. Confirmatory microprobe analysis of this ash will be done in the near future. The average rate of deposition is then estimated as 1.0±0.3 mm/year; and samples taken each 10cm would represent 100±30 years intervals, while the 1cm thick samples averages of 10±3 years.

This corrected chronology would explain why the cores do not display a thick Mazama Ash horizon, usually found in lakes of the region (e.g. Fairfax and Goldeye lakes). The basal reworked ash could then represent Mazama tephra being eroded from the watershed.

The base of Core 2 was already deposited under water, as indicated by its fossils, and Core 1 characteristics (e.g. laminations, diatoms) indicate that the lake was not significantly shallower than today, when the basal portion of the cores was being deposited. On the other hand, the bottom of the east end is composed of loose shale fragments, and is very steep (moraine?), and could have been subjected to mass movements in the past, particularly if mass input

from an adjacent gorge on the south side causes instability (this gorge communicates the Mary Gregg Lake valley with a higher hanging amphitheater valley). Therefore, the basal gravel found in Core 1 could represent a slump or turbidite deposited around 6000±200 BP, and not the original post-glacial bottom of the lake (M. Bombin, personal communication), because major deglaciation was certainly completed before 10,000-9000 BP (e.g. Luckman & Osborn, 1978). Additionally, Core 2, taken far from the probable maximum extent of the density current, is possibly not complete (the piston corer was operated manually), and, therefore, cannot be used as evidence to confirm or reject such hypothesis.

The reason for apparently older dates could be contamination by organic materials and/or incorporation of dead carbon from spring and ground water by aquatic organisms (Olsson in Berglund, 1979; Deevey et al., 1954; Donner et al., 1971). Coal particles are clearly observed only in Core 2, which could explain, at least in part, the larger shift in the dates of this core. Macrophytes, which can incorporate bicarbonate (high in Mary Gregg Lake springs, ground and lake waters), would produce older dates; and a larger contribution of these aquatic plants to the carbon of Core 2, plus coal contamination, explains possibly better the date errors. The absence of pre-Quaternary palynomorphs precludes its use to indicate coal contamination (as suggested by Nambudiri et al., 1980) in

Core 1. Dead aquatic CO_2 could be the main cause of error in Core 1.

This is a good example of the problems that arise when dating cores from lakes where the aquatic carbon available for photosynthesis is not in equilibrium with atmospheric CO_2, and/or when allochthonous older carbon is part of the clastic contribution to the lake sediments. The common practice of establishing chronologies based on a few radiocarbon dates, or even a single basal date, should be examined very critically. It is suggested that surficial sediment samples should be dated whenever possible, to evaluate potential errors, particularly in hard water and/or bicarbonate rich lakes.

Tephrochronology in the area is particularly complicated by the existence of many Holocene ashes, some of them not even identified yet, and by favorable topographic conditions for reworking.

4.2 Paleodynamics of the watershed

In the subsequent text, unless otherwise indicated, the correlation coefficients referred to are Spearman's rho (computed by M. Bombin). This non-parametric statistic was selected because it neither depends upon a normal distribution (some of the variables in this study are not normally distributed), or the metric quality of interval scales. Rho1 will denote correlation coefficients for Core

1, and rho2 for Core 2. All reported rho values are significant at the 0.001 level.

The pollen/spores data suggest that in general terms the watershed has been dominantly covered by boreal forest for the last 6000 years.

There is a wide range of climatic conditions under which boreal forest thrives. In the case of Mary Gregg Lake area ("middle lower subalpine zone"), really drastic changes would have to take place in order to alter dramatically its general vegetation cover. On the other hand, compositional changes through time certainly happened, in response not only to the climate, but to other successional factors as well. However, due to the nature of the boreal forest palynological record, with a few absolutely dominant species, it would be necessary to count very large pollen sums, to clearly unravel possible vegetational changes. Some general compositional changes are, however, suggested by the available record. Myricaceae/Corylaceae ocurrence exclusively below 400cm in Core 1, could be related to more open woods and/or more mesic conditions locally, before 3,250 BP. Higher NAP and alder before ca. 3500 BP in Core 2, also points to more open forests. Pine trended to increase its proportions upwards in the core (rho1(depth x pine)=-.53, rho2(depth x pine)=-.75); alder to decrease (rho1(depth x alder)=.60, rho2(depth x alder)=.64); and spruce to decrease (clear only in Core 2, rho2(depth x spruce)=.55).

The post-Mazama pollen data from Fairfax Lake (another Foothills lake, about 40 km southwest of Mary Gregg Lake) presented by Schweger et al. (in press), is quite similar to my results. The presence of a tephra horizon at 285cm in Fairfax Lake after the 7cm thick Mazama Ash (477-470cm) (D.R. Kvill personal communication), which could be contemporaneous with the Mary Gregg Lake main ash, reinforces the above mentioned correlation between the two lakes.

Slope instability continued for some time after the hypothesized basal slide, as indicated by lenses of coarse materials (gravel, plant detritus) found in Core 1 until about the 550cm level (ca. 4500±200 BP).

Calcium, magnesium, aluminum, and to a lesser extent potassium are correlated to depth (rho1(Ca x depth)=.83, rho2(Ca x depth)=.60; rho1(Mg x depth)=-.60, rho2(Mg x depth)=-.52; rho1(Al x depth)=-.71 rho2(Al x depth)=-.52; rho2(K x depth)=-.45) and, therefore, the correlation among those variables is probably in large extent due to their mutual relationship with depth (time).

The high positive correlation of K, Mg, and Al (rho1(K x Mg)=.61, rho2(k x Mg)=.62; rho1(K x Al)=.68, rho2(K x Al)=.65; rho1(Mg x Al)=.87, rho2(Mg x Al)=.85), suggests, that they could be related to a common factor, possibly to illite (hydromica) eroded from the north slope (the Blackstone Shale is rich in this clay mineral). The trend to higher K, Mg, and Al with time is possibly linked to

augmented eluviation on the steep slopes and runoff during the spring after about 4000±200 BP.

Calcium is negatively correlated to the above mentioned terrigenous sedimentation indicators (e.g. rho1(Ca x Al)=-.68, rh2(Ca x K)=-.59), and its stratigraphic behavior is better explained by factors operating within the aquatic system.

The Na bulge after the main volcanic ash, indicates that reworking and mobilization of the tephra blanket in the basin continued to be significant for about 500-1000 years after the ash fall.

Judging from the higher C:N ratio, the watershed organic input into the lake was less significant between 4000 and 1000 BP, which could reflect higher soil stability during this time.

4.3 Paleodynamics of the aquatic system

Carbon, nitrogen, sulfur, a-pigments, and carotenoids, commonly used as paleoproductivity indicators, are in general strongly correlated, as can be seen in Table 11. A threefold stratigraphic behavior is clear, suggesting higher productivity between ca. 6000±200 and 3500±200, a decrease between ca. 3500±200 and 1000±200 BP, and again higher productivity after that. The a-pigments:carotenoids ratio suggests a general trend towards less eutrophic conditions from the base upwards. The low correlation between C and the

Table 11 - Correlation of biogeochemical indicators (rho)

	C	N	S	a-pigm.	carot.
C		.31*	.33*	.34*	.40*
N	.79		.74	.74	.72
S	.68	.74		.80	.91
a-pigm.	.83	.86	.76		.92
carot.	.79	.86	.83	.94	

The lower matrix triangle corresponds to Core 1 variables, and the upper to Core 2.
*Not significant at the .001 level.

other variables in Core 2, plus an overall higher C:N ratio than Core 1, indicates a higher input of allochthonous carbon. This is probably to a large extent in the form of coal particles from the Luscar Formation (south slope), given the older radiocarbon dates of Core 2, as already indicated when the chronology problems were discussed. The positive correlation among components usually preserved under anaerobic conditions, indicates a dominance of this kind of bottom environment throughout the history of the lake. The organic provenience of S is also clear.

Iron is related principally to the reducing condition of the sediment, because it is strongly associated with the organic components (rho1(Fe x C)=.67; rho1(Fe x N)=.66, rho2(Fe x N)=.69; rho1(Fe x S)=.80, rho2(Fe x S)=.89; rho1(Fe x a-pigments)=.71, rho2(Fe x a-pigments)=.75; rho1(Fe x carotenoids)=.70, rho2(Fe x carotenoids)=.83). The high correlation between Fe and S suggests that these elements are coprecipitated in the sediment as FeS_2, which is confirmed by the counts of pyrite spherules. The very weak association between Fe and carbon in Core 2, (rho=.22), once again indicates that a good proportion of the ignitable carbon is probably coal (not easily decomposable by anaerobic bacteria).

The dominant reducing sediment conditions kept Mn mobile throughout most of the lake history, making its stratigraphic profile difficult to interpret. From the middle section of both cores upwards, Mn tends to increase

(rho2(Mn x depth)=-.77), but Fe does not, suggesting higher Mn input from the watershed (increasingly higher reduction of soils).

There is no positive relation between Ca and Mg, and both are oppositely correlated with time. This, in combination with the correlation between Ca and carbonate (rho1(Ca x carbonate)=.60), indicates that most of the Ca is present in the form of precipitated $CaCO_3$. In fact, marl bands and effervescence with HCl occur towards the bottom of the cores, where Ca is higher. Considering the following equilibrium expression:

$$Ca^{++} + 2HCO_3^- = H_2O + CO_2 + CaCO_3(s),$$

consumption of CO_2 by micro- and macrophytes, or temperature increase (decreasing solubility of CO_2 and calcite), will cause a shift to the right in the equilibrium equation, precipitating $CaCO_3$. The carbonate stratigraphic profile follows well the productivity indicators in the basal and middle portions of the cores, but does not in the upper portion. This suggests that a combination of biogenic and physical factors were involved in calcite deposition throughout Mary Gregg Lake history. Perhaps the basal marly sediments are better explained by concurrent higher phytogenic activity, and higher summer water temperatures (which also would have a positive feedback effect upon productivity). Other factors, as pH, evaporation, salinity, kinds and amounts of dissolved ions, and diagenetic solubilization of calcite, could be involved, but it is

acknowledged that detailed studies, such as calcite particle morphology and X-ray diffraction, are necessary if a more refined approach to the problem, as that by Kelts & Hsu in Lerman (1978), is aimed.

The positive relation of the sediment pH with carbonate and negative with organic indicators, suggest that those are the major factors controlling that variable. The excellent preservation of diatoms and Chrysophyta cysts throughout the cores, is perhaps an indication that the sediment pH never significantly exceeded 7.

Phosphorus reaches the bottom of lakes sedimented as particulated organic matter, terrigenous minerals and, under relatively oxidant conditions. It can be also coprecipitated with and adsorbed to Fe/Mn oxides, aluminum hydroxides, and clay minerals (Bortleson & Lee, 1972, 1974; Mackereth, 1966). In this situation, the sedimentary concentration of P could reflect changes in the input of this element to the lake system, particularly those induced by human activity (e.g. Bortleson & Lee, 1972), or significant changes in the water and bottom environment. However, in the case of Mary Gregg Lake - where human impact has been so far minimal, and a very anoxic sediment seems to have always predominated, with iron being precipitated as sulfide instead of oxides, and manganese being constantly mobile - the release of P from and migration within the sediment would have been facilitated. As a result, no clear trends are visible, and the very dynamic and complex history of this element is

reflected in erratic stratigraphic profiles, not very significantly correlated with any other of the studied variables in particular; that is, different combinations of factors would be involved in explaining each individual sample. The average of 2.21±1.71 mg P/g dry wt. in Core 1 does not differ significantly from the average watershed and plant composition (2.3 mg/g). On the other hand, the average of 1.33±0.48 mg/g in Core 2, suggests sedimentary release of P to the water system. This difference could indicate that the sediment under non-stratified water (with rapid mixing) is a more important source of P to the lake, than sediment under hypolimnic waters. Also, Core 2 is richer in clean quartz sand, which is very low in P. The peak in the basal portion of Core 1, is explained by the higher concentration of shale and iron oxides. The two other marked peaks at 570 and 420 cm, are due to higher concentration of shale and vivianite. The diagenetic precipitation of this hydrated ferrous phosphate was induced by macroscopic plant detritus (intense reducing center), a phenomenon explained by Mackereth (1966). This author also suggested that this is a relatively slow process, which is in agreement with the fact that this mineral is present only in the older portion of this core.

The average Zn and Cu concentrations in Core 1 and Core 2 samples are not very significantly different from the local watershed sources. Exceptions are the peaks at 400 and 310 cm in Core 1, and 245 and 185 cm in Core 2, which can

actually serve for stratigraphic correlation, and show that the increases represent a general phenomenon within the lake. The Zn concentration in these samples far exceeds the local terrigenous sediments, and probably do not represent redox changes, because they occurred simultaneously in the deep and shallow portions of the lake, and the other redox indicators do not show any comparable oscillations. They might be related to some biogenic factor, but this is a problem that needs further study. Zn and Cu are positively correlated in Core 1 (rho1(Zn x Cu)=.58). In Core 2, although they do not yield an overall correlation, the middle sections display coincident peaks.

Using basically the data provided by Bradbury (1971, 1975), Bradbury & Whiteside (1980), Bradbury & Winter (1976), Cholnoky (1968), Florin (1970), Foged (1954), Haworth (1969, 1972, 1976, 1977), Hickman (1974, 1975), Hickman et al. (1978), Hustedt (1937-39), Merilainen (1969, 1971), Patrick (1977), Patrick & Reimer (1966, 1975), Round (1957a, 1957b, 1960, 1961, 1964, 1973), all the identified diatoms were grouped according to preferential habitat, pH, and trophic status, producing the profiles of proportions depicted in Figure 21 and 22 . These show that the benthic taxa always dominated, even in the deep spot, indicating clear waters throughout the history of the lake. Planktonic varieties have higher peaks before 3500±200 BP and after 1000±200 BP, in Core 1; inversely, in Core 2 they are only slightly more abundant between 3500±200 and 1000±200 BP, but

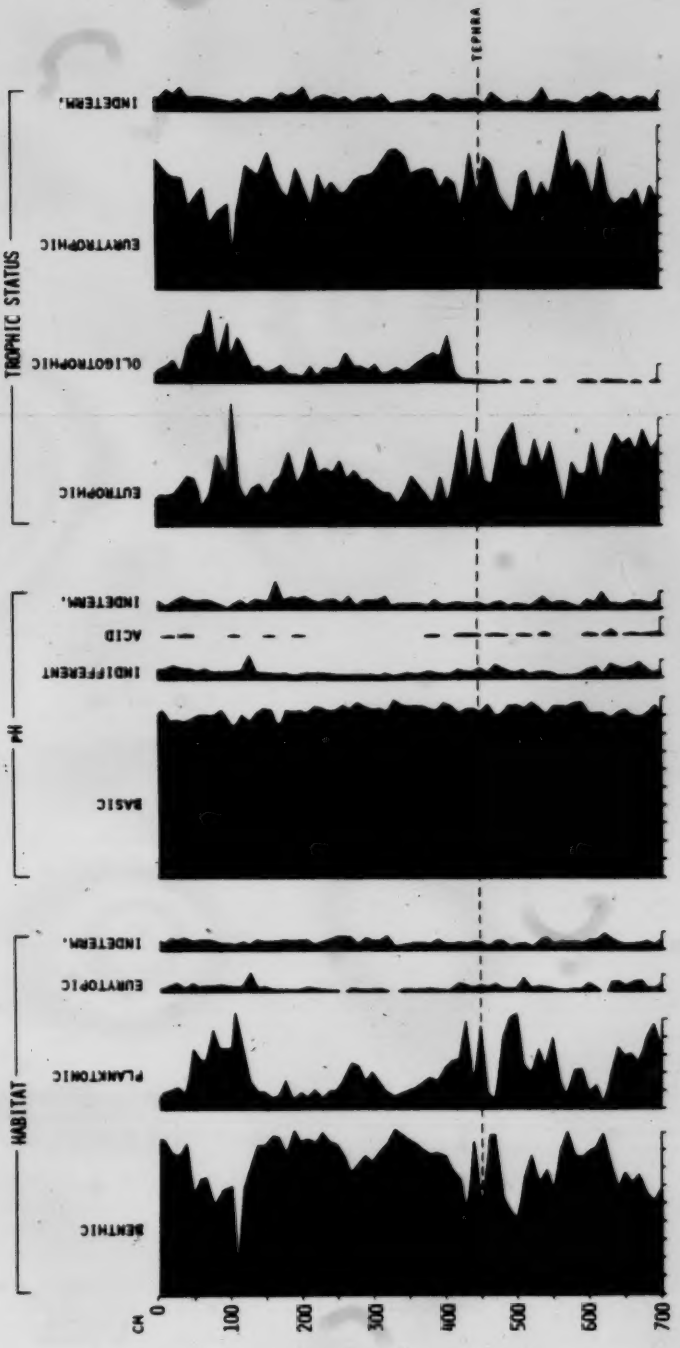

FIGURE 21 - CORE 1 ECOLOGICAL STRATIGRAPHY OF DIATOMS.

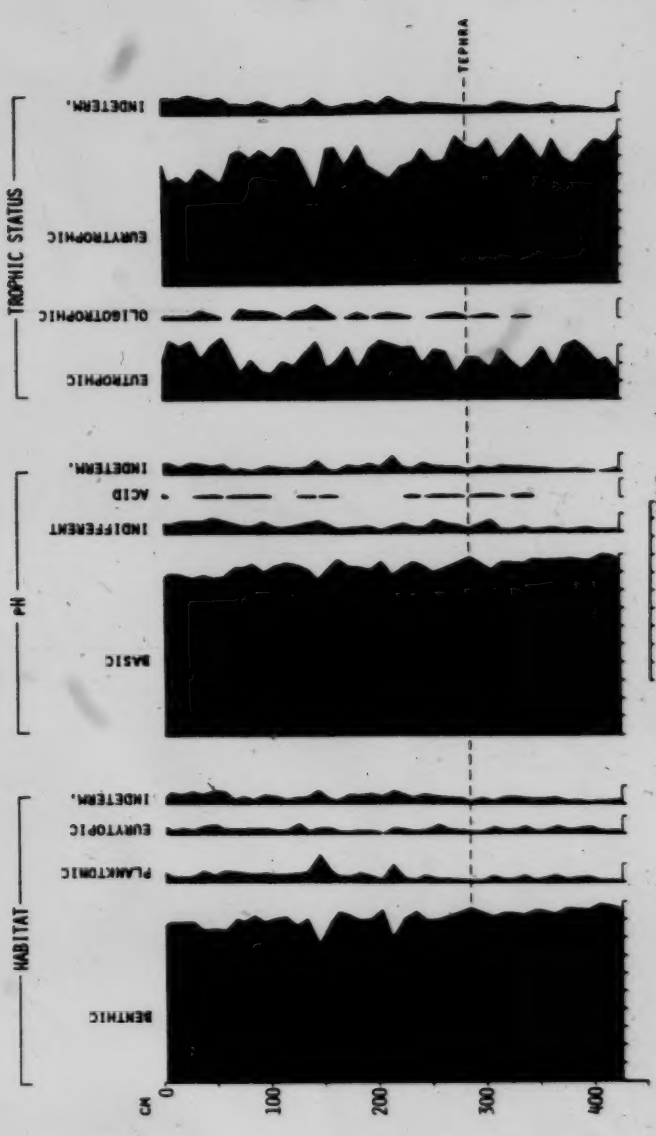

FIGURE 22 - CORE 2 ECOLOGICAL STRATIGRAPHY OF DIATOMS.

this is explained basically by the particular increase of *Cyclotella comta*. Taxa which prefer pH towards the basic side of the scale always predominated overwhelmingly. There is a hint that more pH indiferent diatoms where slightly more abundant before 3500±200 BP, and have increased again in the last 1000±200 years. As seen from Core 1, before ca. 3500±200 BP the planktonic indicators (Centrales + Araphidineae) of more eutrophic conditions dominated. Afterwards, they are succeeded by more oligotrophic indicators in balance with others (Araphidineae) usually found in more eutrophic conditions. In Core 2, this is also observed, although not so clearly, because of the locally more abundant recycled nutrients in shallow waters (*Stephanodiscus hantzschii*, for example occurs locally in small populations at recent times in Core 2). Most of the benthic species, particularly the epipelic that dominate Mary Gregg Lake's record, cannot be unmistakably correlated to the trophic status of the open water, also because of the nutrient-rich microenvironment closer to the sediment (Round, 1960).

Autoecologically, the Centrales *Stephanodiscus hantzschii* (rho1(S.h. x depth)=.82) and *Cyclotella comta* (rho1(C.c. x depth)=-.76, rho2(C.c x depth)=-.75) are the most clear indicators respectivelly of more eutrophic and oligotrophic conditions, which supports the idea that the Araphidineae/Centrales index is not a universally valid indicator of trophic status, as pointed out for example by

Battarbee in Berglund (1979), and by Brugam (1979). Other individual species that are also abundant during the basal phase of more eutrophic conditions (before ca. 3500±200 BP) are: *Fragilaria construens* var. *binodis*, *Synedra acus* var. *radians*, *Asterionella formosa*, *Stephanodiscus astraea* var. *minutula*, and *Cyclotella kutzingiana*. The growing requirements of these diatoms could have been met if a longer ice-free season, and higher water temperatures occurred at Mary Gregg Lake. The wide range of represented varieties that bloom at different times (Patrick, 1977), could actually support this model. The communities present before ca. 3500±200 BP, with high proportions of *Stephanodiscus hantzschii*, suggests higher total water phosphorus and alkalinity (Brugam, 1979).

The increase in the epiphytic diatoms *Amphora ovalis* var. *pediculus*, *Achnanthes lanceolata* var. *rostrata*, and *Achnanthes exigua*, between 3500±200 and 1000±200 BP, agrees with the idea of more transparent waters during this time.

The *Myriophyllum* highs before ca. 3500±200 BP could also indicate longer ice-free growing season and higher summer water temperatures (Haag, 1979; Haag & Gorham 1977). It should not be entirely related to very significant lower water levels, because in that case the littoral area would have been actually reduced, and would contradict other indicators discussed before. The same conditions seem to have favored other macrophytes as well at that time(e.g. *Potamogeton* and *Ranunculus* represented by abundant seeds in

Core 2).

The more eutrophic status of the lake before 3500±200 BP is also corroborated by the higher abundances of Desmidiaceae, *Tetraedron*, and Chrysophyta. These, associated to richer remains of Cladocera (anatomical parts and hiphippia), *Plumatella* statoblasts, molluscs, fish bones, and all the other previously discussed indicators, also suggest higher productivity at that time.

4.4 Integration

A cluster analysis of the sampled core levels by Ward's method (Wishart, 1978) was performed by M. Bombin, using the following 42 variables for classification: Na, K, Ca, Mg, Al, Zn, Cu, Fe, Mn, C, N, P, S, carbonates, a-pigments, carotenoids, pH, fines (silt + clay), *Fragilaria construens*, *F. construens* var. *venter*, *F. construens* var. *binodis*, *F. pinnata*, *F. brevistriata*, *Amphora ovalis* var. *pediculus*, *Achnanthes lanceolata* var. *rostrata*, *A. exigua*, *Rhopalodia gibba*, *Tabellaria fenestrata*, *Fragilaria crotonensis*, *Synedra acus* var. *radians*, *Asterionella formosa*, *Stephanodiscus astraea* var. *minutula*, *S. hantzschii*, *Cyclotella kutzingiana*, *C. comta*, *Pinus*, *Picea*, *Abies*, *Alnus*, *Betula*, NAP, and *Myriophyllum*. The resultant dendrograms are depicted in Figures 23 and 24 . The list of cluster groups in stratigraphic sequence is shown in Tables 12 and 13 . The results of this classification procedure

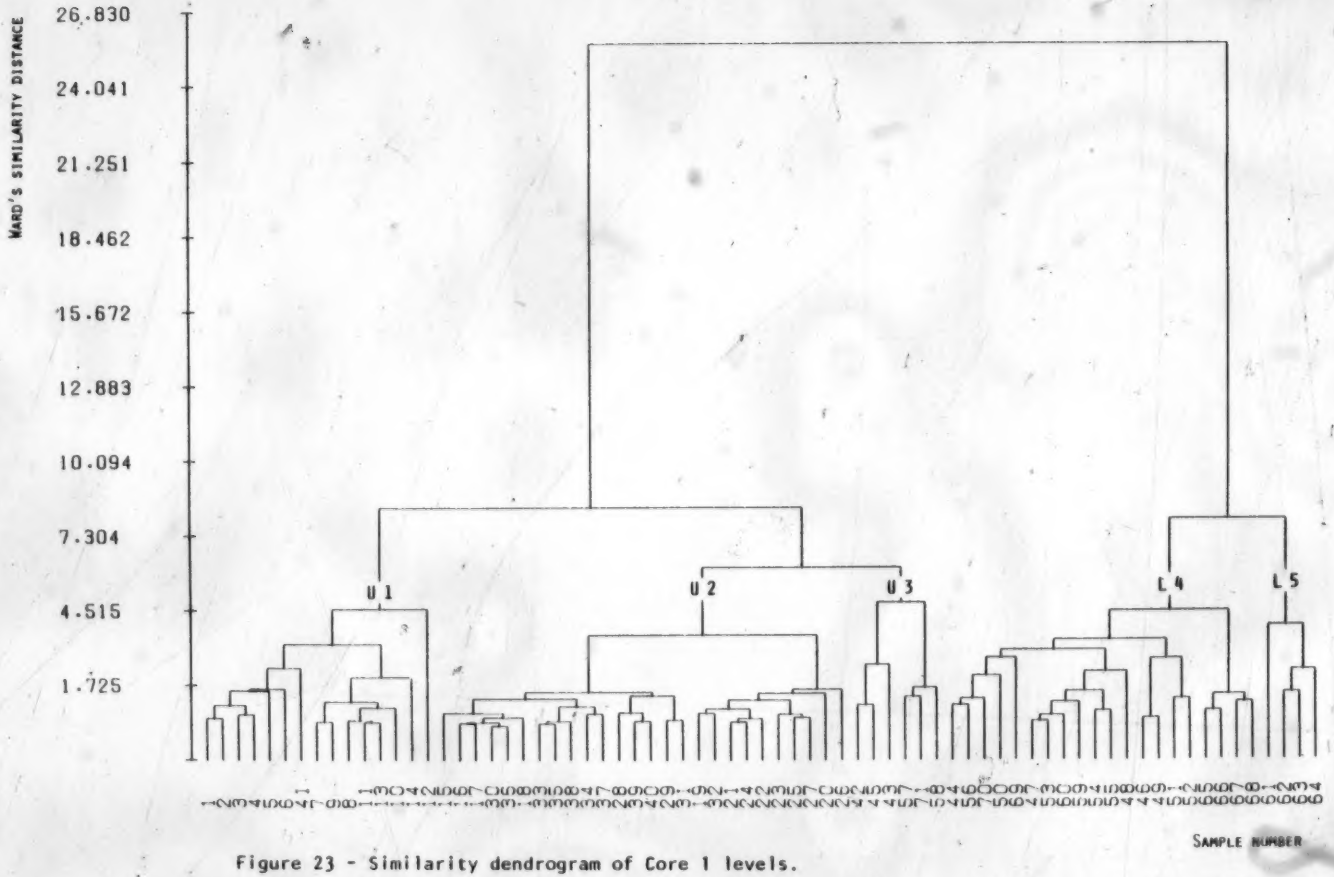

Figure 23 - Similarity dendrogram of Core 1 levels.

Figure 24 - Similarity dendrogram of Core 2 levels.

Table 12 - Core 1 similarity clusters in stratigraphic sequence

Sample	Depth*	Cluster	Sample	Depth*	Cluster	Sample	Depth*	Cluster
1	5	U 1	25	240	U 2	49	480	L 4
2	10	U 1	26	250	U 2	50	490	L 4
3	20	U 1	27	260	U 2	51	500	L 4
4	30	U 1	28	270	U 2	52	510	L 4
5	40	U 1	29	280	U 2	53	520	L 4
6	50	U 1	30	290	U 2	54	530	L 4
7	60	U 1	31	300	U 2	55	540	L 4
8	70	U 1	32	310	U 2	56	550	L 4
9	80	U 1	33	320	U 2	57	560	U 3
10	90	U 1	34	330	U 2	58	570	U 3
11	105	U 1	35	340	U 2	59	580	L 4
12	110	U 1	36	350	U 2	60	590	L 4
13	120	U 1	37	360	U 2	61	600	L 5
14	130	U 1	38	370	U 2	62	610	L 5
15	140	U 2	39	380	U 2	63	620	L 5
16	150	U 2	40	390	U 2	64	630	L 5
17	160	U 2	41	400	U 1	65	640	L 4
18	170	U 2	42	410	U 3	66	650	L 4
19	180	U 2	43	420	U 3	67	660	L 4
20	190	U 2	44	430	L 4	68	670	L 4
21	200	U 2	45	440	U 3	69	680	L 4
22	210	U 2	46	450	L 4	70	690	L 4
23	220	U 2	47	460	L 4	71	700	U 3
24	230	U 2	48	470	L 4			

*cm

----- major similarity breaks

Table 13 - Core 2 similarity clusters in stratigraphic sequence

Sample	Depth*	Cluster	Sample	Depth*	Cluster
1	5	U 1	23	215	U 3
2	10	U 1	24	225	U 3
3	20	U 1	25	235	U 3
4	30	U 1	26	245	U 3
5	40	U 1	27	255	U 3
6	50	U 1	28	266	U 3
7	60	U 1	29	276	U 3
8	70	U 2	30	286	L 4
9	77	U 2	31	296	L 4
10	87	U 2	32	306	L 4
11	97	U 2	33	316	L 4
12	107	U 2	34	326	L 4
13	117	U 2	35	336	L 4
14	127	U 2	36	345	L 4
15	137	U 2	37	355	L 4
16	147	U 1	38	365	L 4
17	157	U 1	39	375	L 4
18	165	U 2	40	385	L 4
19	175	U 3	41	395	L 4
20	185	U 3	42	405	L 4
21	195	U 3	43	415	L 4
22	205	U 3	44	425	L 4

*cm

----- major similarity breaks

illustrate well the proposed structure of the data in a threefold stratigraphic scheme.

From this analysis, and by comparison of the suggested chronologies, the correlation presented in Figure 25 is accepted.

In summary, the model emerging from this research, considers that the available cores contain information about the last 6000 years of the history of Mary Gregg Lake, which can be interpreted basically as representing three different ecological situations. Between 6000±200 BP and 3500±200 BP the lake would have been more eutrophic and productive; followed by a shift towards more oligotrophic conditions between 3500±200 BP and 1000±200 BP; and, finally another shift towards the present mesotrophic conditions. The model also accepts water depths as relatively high during the time span covered by the cores (i.e. not lower than about 4m).

To accommodate this reconstruction, a threefold parallel hydrologic sequence is also suggested. An older period, between 6000±200 and 3500±200 BP, of balanced inflow/outflow (higher water residence time and evaporation), with longer ice-free season and possible higher water temperatures, which resulted in more efficient mixing and circulation of nutrients, as well as more successful reproduction of macrophytes. An intermediate period of elevated outflow after melting, and lower evaporation, associated to a shorter and colder growing season with nutrient depleted waters, between 3500±200 BP

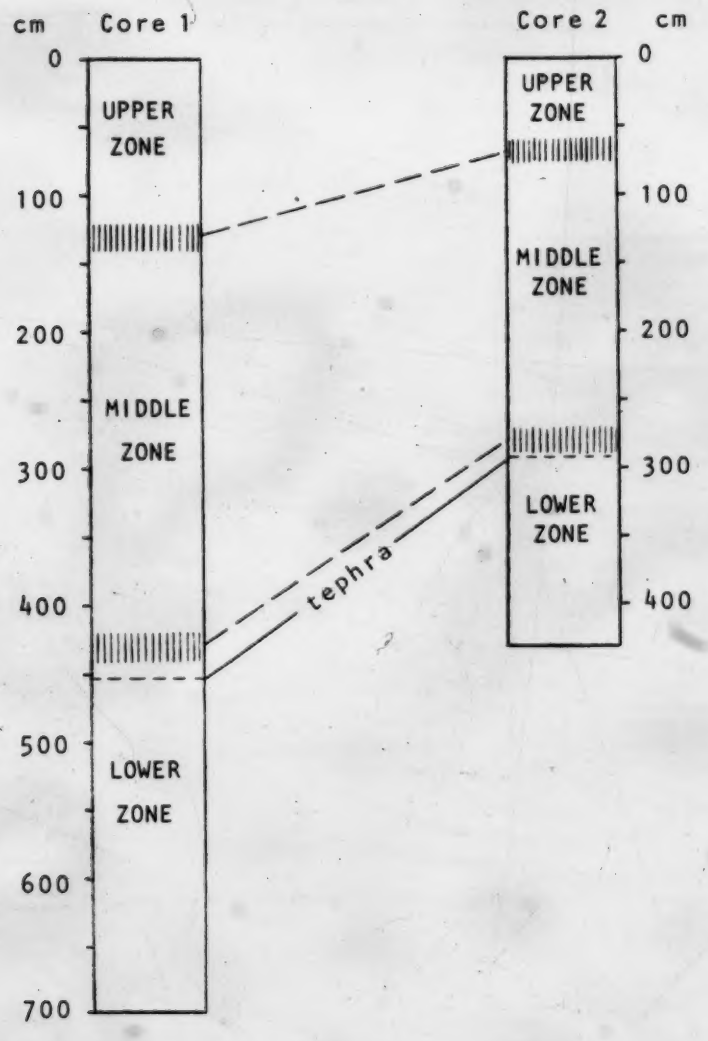

Figure 25 - Stratigraphic correlation between Cores 1 and 2.

and 1000±200 BP. And finally, a period when outflow is again reduced, and conditions result again in somewhat higher concentrations of water nutrients, and a more favorable growing season.

The paleoclimatic states related to this sequence, could be roughly reconstructed as: relatively more mesic conditions before 3500±200 BP; followed by a cooler (summers?) and wetter (winters?) regime than today, between 3500±200 BP and 1000±200 BP; and a final interval towards the present situation after 1000±200 BP; all separated by relatively rapid transitional periods, as contended for example by Wendland & Bryson (1974). Within this same school of thought of step-wise climatic changes, one can also argue that two changes of pattern happened: one, some time between 6000-5000 BP, from more mesic to cooler and wetter conditions; and another at about 2500±200 BP to a less cooler and wetter regime; and that the stratigraphic profiles of the available indicators in fact reflect the respective successional response lags, after the rapid climatic change. Alternatively, another way of describing the observed three-zoned sequence, is considering it as a reflection of a gradual environmental cycle, with two changes of phase, trending initially from more mesic to cooler and wetter conditions, from the basal section to about 2500±200 BP; and from then on reversing the trend towards the present situation. This would represent the Neoglacial cycle (*sensu* Wright, 1976). It is even possible

to argue that some paleoclimatic changes could have been abrupt (e.g. around 3500 and 1000 BP), and others gradual (e.g. around 2500 BP). The available data does not allow a clear decision about the different possibilities, principally because of the already mentioned lags involved in changes of the indicators with respect to climatic change.The seemingly abrupt changes in some of the biogenic indicators, could also be explained by the climatic gradualists as a result of the existence of thresholds in biological and certain chemical responses. In summary, different combinations of climatic change pattern and behavior of indicators response, can lead to very similar stratigraphic records. This, plus the usual chronological uncertainties, illustrates the sources of classical polemics in paleoecology.

Most palynological work in Western Canada has shown that the Hypsithermal climatic interval (*sensu* Wright, 1976), extended aproximately from 9500-9000 BP to 6500-5000 BP (e.g. Alley, 1976; Ritchie, 1976; and Schweger et al., in press). If the proposed chronology for Mary Gregg Lake is correct, only the latest effects of this warm episode, which could have lasted until about 3500±200 BP, would be represented in the basal portion of the recovered cores. The trend towards cooler and wetter conditions in the adjacent area of Jasper National Park, after 6000-5000 BP, is also supported by Luckman & Osborn (1978).

The paleoclimatic oscillations suggested above for the Mary Gregg Lake area, were apparently not of a magnitude such as to alter significantly the general vegetation of the watershed, and this also points out that, in this case, the lake system is more sensitive to less pronounced environmental changes. Up to now, human impact upon Mary Gregg Lake has not been of a large magnitude, but the history of the lake indicates that it can easily become a powerful agent of change. Therefore, all future alterations that can potentially modify the hydrology of the system, or the inputs from the watershed, should be carefully monitored, including the routine analysis of biological indicators.

Volcanic ash microprobe, radiocarbon, and stable isotope analyses are scheduled for the near future, to help clarifying the chronology problems.

In order to test the hypothesis that the paleoecological record provided by Cores 1 and 2 is incomplete, and possibly recover the older postglacial history of the lake, an additional core is planned. This should be taken at an intermediate point between Cores 1 and 2, if possible with a piston corer mechanically driven.

More detailed limnological studies of the lake are necessary, to provide a better basis for further paleolimnological interpretations, and prediction of possible future trends.

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